PB83-190272

Resource Conservation and Utilization in Animal Waste Management. Volume I Utilization of Animal Manures as Feedstuffs for Livestock and Poultry

Cornell Univ.
Ithaca, NY

Prepared for

Robert S. Kerr Environmental Research Lab.
Ada, OK

Mar 83

U.S. Department of Commerce
National Technical Information Service
NTIS

EPA-600/2-83-024a
March 1983

PB83-190272

RESOURCE CONSERVATION AND UTILIZATION IN ANIMAL WASTE MANAGEMENT - VOLUME I

Utilization of Animal Manures as Feedstuffs for Livestock and Poultry

by

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PAGE NUMBER
EPA Form 3350-4 (4-80)
(PREVIOUSLY EPA FORM 257)
TYPING GUIDE SHEET

TECHNICAL REPORT DATA

(Please read Instructions on the reverse before completing)

1. REPORT NO. EPA-600/2-83-024a	2.	3. RECIPIENT'S ACCESSION NO. PB83 190272
4. TITLE AND SUBTITLE Resource Conservation and Utilization in Animal Waste Management - Volume I Utilization of Animal Manure as Feedstuffs for Livestock and Poultry		5. REPORT DATE March 1983 6. PERFORMING ORGANIZATION CODE
7. AUTHOR(S) Thomas E. Pilbeam, John H. Martin, Jr., and Raymond C. Loehr		8. PERFORMING ORGANIZATION REPORT NO.
9. PERFORMING ORGANIZATION NAME AND ADDRESS Department of Agricultural Engineering Cornell University Ithaca, NY 14853		10. PROGRAM ELEMENT NO. APBC 11. CONTRACT/GRANT NO. R-806140
12. SPONSORING AGENCY NAME AND ADDRESS U.S. Environmental Protection Agency Robert S. Kerr Environmental Research Laboratory P.O. Box 1198 Ada, OK 74820		13. TYPE OF REPORT AND PERIOD COVERED Final, Vol. I 14. SPONSORING AGENCY CODE EPA/600/15

15. SUPPLEMENTARY NOTES

16. ABSTRACT

Use of animal manures as feedstuffs has been suggested as a method to: (1) reduce the cost of producing animal products, and (2) reduce or alleviate potential air and water pollution problems associated with animal manures.

This study assembled, critically reviewed and analyzed reported information pertaining to the nutrient characteristics of animal manures and their nutritive value when utilized as feedstuffs in feeding trials. The evaluation focused on dairy cattle, beef cattle, and caged laying hen manures, and broiler litter utilized as feedstuffs for cattle and poultry.

Based on the results of feeding trials, the assessment of the nutritive value of animal manures indicated that generally less than 25% of the manures could be incorporated into rations without adversely affecting animal performance. The estimated economic value of the manures was highly variable. In some instances their fertilizer values exceeded their value as a feedstuff.

The utilization of animal manures as feedstuffs does not appear to be a waste management practice that reduces potential environmental quality problems caused by the discharge of animal manures. Only a small quantity of animal manures may be incorporated into animal rations and the potential pollution abatement impact would be minimal.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
Agricultural Wastes Animal Husbandry Waste Disposal Animal Nutrition	Refeeding Systems Animal Wastes Cattle Swine Poultry Economic Literature Survey	02/A, B, C, E

18. DISTRIBUTION STATEMENT Release Unlimited	19. SECURITY CLASS *(This Report)* Unclassified	21. NO. OF PAGES 337
	20. SECURITY CLASS *(This page)* Unclassified	22. PRICE

DISCLAIMER

Although the research described in this article has been funded wholly or in part by the United States Environmental Protection Agency through contract or grant R-806140 to Cornell University, it has not been subjected to the Agency's required peer and policy review and therefore does not necessarily reflect the views of the Agency, and no official endorsement should be inferred. Mention of trade names or commercial products does not constitute endorsement or recommendation for use.

FOREWORD

EPA is charged by Congress to protect the Nation's land, air and water systems. Under a mandate of national environmental laws focused on air and water quality, solid waste management and the control of toxic substances, pesticides, noise, and radiation, the Agency strives to formulate and implement actions which lead to a compatible balance between human activities and the ability of natural systems to support and nurture life. In partial response to these mandates, the Robert S. Kerr Environmental Research Laboratory, Ada, Oklahoma, is charged with the mission to manage research programs to investigate the nature, transport, fate, and management of pollutants in ground water and to develop and demonstrate technologies for treating wastewaters with soils and other natural systems; for controlling pollution from irrigated crop and animal production agricultural activities; for controlling pollution from petroleum refining and petrochemical industries; and for managing pollution resulting from combinations of industrial/industrial and industrial/municipal wastewaters.

This phase of the project was initiated to evaluate the use of animal manures as feedstuffs for refeeding back to animals. This study assembled, critically reviewed, and analyzed reported information pertaining to the nutrient characteristics of animal manures and their nutritive value when utilized as feedstuffs in feeding trials. This information indicates that only a small portion of the collectable animal manure could be utilized as feestuffs and is useful in determining optimal practices which will lead to the development of Best Management Practices for this phase of animal waste management systems.

Clinton W. Hall

Clinton W. Hall, Director
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ABSTRACT

Use of animal manures as feedstuffs has been suggested as a method to: (1) reduce the cost of producing animal products, and (2) reduce or alleviate potential air and water pollution problems associated with animal manures. This utilization of manures is dependent upon their nutrient composition and their ability to be substituted for conventional feedstuffs without adversely affecting animal performance. Pollution abatement benefits could be realized if sufficient quantities of animal manures were utilized as feedstuffs.

This study assembled, critically reviewed and analyzed reported information pertaining to the nutrient characteristics of animal manures and their nutritive value when utilized as feedstuffs in feeding trials. The evaluation focused on dairy cattle, beef cattle, and caged laying hen manures, and broiler litter utilized as feedstuffs for cattle and poultry. These types of manures received emphasis because they represent approximately 85% of the economically recoverable manure produced annually in the United States. The economic incentives for the utilization of animal manures as feedstuffs were determined by the assessment of animal performance from feeding trial information and the determination of economic benefits (such as reduced feed costs and increased animal selling price).

The assessment of the nutrient characteristics of dried poultry waste (DPW), broiler litter, and dairy cow and beef cattle manure indicated that when these are utilized as a feedstuff for ruminants: (1) they are more comparable to silages and hays than to protein or energy feedstuffs, and (2) they have an estimated economic value of about $58 to $80 per tonne (dry matter basis). The assessment of the nutrient characteristics of DPW indicated that when DPW is utilized as a feedstuff for laying hens: (1) it is best considered as a source of minerals and amino acids, and (2) it has an estimated economic value of about $117 per tonne (dry matter basis).

The lack of reported nutrient characteristics for other processed animal manures (aerobically and anaerobically digested manures, manure screenings, and Cereco products) prevented the identification of analogous conventional feedstuffs and an estimation of the nutrient value of the other processed manures. An exception was the Cereco silage product (CI) which was estimated to have an economic value of about $58 to $80 per tonne (dry matter basis).

Based on the results of feeding trials, the assessment of the nutritive value of animal manures indicated that generally less than 25% of the manures could be incorporated into rations without adversely affecting animal performance. The estimated economic value of the manures was highly variable. In some instances their fertilizer values exceeded their value as a feedstuff. The estimated economic value of DPW as a feedstuff exceeded its nutrient composition and fertilizer values, but only when small quantities were incorporated into a ration or diet.

The assessment of the nutritive value of other processed animal manures, based on the results of feeding trials, indicated that aerobically digested manure, manure screenings, and Cereco products may have value as a feedstuff. Due to the paucity of feeding trial results, the estimated economic values of these other processed manures could not be determined. The utilization of anaerobically digested animal manures as feedstuffs did not appear feasible based on reported feeding trial results.

The utilization of animal manures as feedstuffs does not appear to be a waste management practice that reduces potential environmental quality problems caused by the discharge of animal manures. Only a small quantity of animal manures may be incorporated into animal rations and the potential pollution abatement impact would be minimal.

This work was submitted in partial fulfillment of contract no. 806140 by Cornell University under the sponsorship of the U.S. Environmental Protection Agency. This report covers the time period of October 1978 to April 1980.

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LIST OF ABBREVIATIONS

ABBREVIATIONS

ADE --apparent digestible energy
ADF --acid detergent fiber
ADG --average daily gain
CI --Cereco silage product
CII --Cereco protein product
CIII --Cereco soil conditioner
CF --crude fiber
CP --crude protein
DBL --dried broiler litter
DCF --digestible crude fiber
DCP --digestible crude protein
DEE --digestible ether extract
DM --dry matter
DNFE --digestible nitrogen-free extract
DP --digestible protein
DPW --dried poultry waste
EBL --ensiled broiler litter
EE --ether extract
HRT --hydraulic retention time
ME --metabolizable energy
NDF --neutral detergent fiber
NE --net energy
NFE --nitrogen-free extract
NPN --nonprotein nitrogen
ODML --oxidation ditch mixed liquor
TDN --total digestible nutrients
TKN --total Kjeldahl nitrogen
TP --true protein

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ACKNOWLEDGEMENTS

The technical assistance of Drs. Peter Van Soest and James Robertson, Cornell University, is sincerely appreciated.

Special appreciation goes to Karen Rizzo and Colleen Martin for patient secretarial and editorial assistance throughout the project.

The authors are particularly grateful for the comments and suggestions made by the following individuals as well as their review of an early draft of this report:

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SECTION 1

INTRODUCTION

The use of animal manures as feedstuffs is conceptually attractive because it has the potential to reduce production costs and to provide a partial solution to manure management and environmental problems. For these reasons, a number of nutritional and economic studies have evaluated the use of animal manures as feedstuffs.

Interest in the use of animal manures as a component of animal feed is not new. Research on this topic occurred in the 1940s with early interest focusing on dairy and poultry manures as sources of "an unidentified growth factor," riboflavin (vitamin B_2), and vitamin B_{12}. A number of studies demonstrated the beneficial effect that resulted from the inclusion of dairy and poultry manures in the poultry diets of that period (Lamoreux and Schumacher, 1940; Hammond, 1942; Rubin *et al.*, 1946).

In the 1950s, interest in manures as feedstuffs focused on the use of poultry litter as a source of crude protein in rations for beef cattle (Noland *et al.*, 1955; Southwell *et al.*, 1958). Positive results were noted when a portion of the cattle ration was replaced by poultry litter.

In the 1960s, interest in animal manures as feedstuffs expanded to include beef cattle manure, as well as poultry litter and manure. Anthony (1966, 1968, 1969) incorporated feedlot beef cattle manure into cattle rations and also developed the concept of wastelage (57 parts feedlot manure to 43 parts ground hay) as a silage substitute for cattle. Interest in broiler litter involved further delineation of its nutritive value using protein digestibility studies (Brugman *et al.*, 1964; Fontenot *et al.*, 1964, 1966). The use of dried caged laying hen manure in laying hen diets produced positive results (Quisenberry and Bradley, 1968; Flegal and Zindel, 1969).

In the 1970s, interest in animal manures as feedstuffs focused on the continued delineation of their nutritive value via digestibility and nitrogen balance studies (Anthony, 1971; Smith, 1971, 1973a, 1973b).

Thus, over the past forty years, the use of animal manures as feedstuffs has evolved from the detection of "an unknown growth factor" to the identification of their nutrient content and their nutritional value.

Although a substantial data base has been established for the use of animal manures as feedstuffs, the information is not consistent and the value of animal manures as feedstuffs is not completely clear. Similarly,

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the delineation of possible pollution control benefits from the use of animal manures as feedstuffs also is not clear. The extent to which the costs of air and water pollution control and the alleviation of waste disposal problems could be reduced by the use of animal manures as feedstuffs needs to be clarified.

The nutritional basis for utilizing manures as feedstuffs appears to be reasonable when the nutrient composition of these materials is compared with conventional feedstuffs. As a source of nitrogen and minerals (Table 1), manures compare favorably to conventional feedstuffs.

When the nutrient composition of the collectible animal manures is considered,livestock and poultry manures represent a significant potential feed source for animal agriculture. It has been estimated that the collectible quantity of manure voided annually by livestock and poultry in the United States is 633 million tonnes (Lauer, 1975). This quantity of manure represents 3.2 million tonnes of manurial nitrogen, which exceeds the crude protein content of the 1972 United States soybean crop.

When the economic value of manure is based on its value as a source of animal or plant mutrient the results suggest that manures may have greater value as feedsutffs. Smith and Wheeler (1979) concluded that the economic value of manures as a source of protein in animal feeds is many times greater than as a source of plant nutrients. Using least-cost feed-formulation techniques, materials, estimated values ranged from $24 to $39 per tonne.

TABLE 1. NUTRIENT COMPOSITIONS OF ANIMAL MANURES AND CONVENTIONAL FEEDSTUFFS (Ensminger and Olentine, 1978)

	Crude Protein %	Crude Fiber %	Ether Extract %	Ash %	Calcium %	Phosphorus %	Metabolizable Energy kcal/kg	
							Ruminants	Poultry
Cattle manure without bedding, dehydrated	13	28.4	2.9	19.1	2.02	0.71	1,770	--
Poultry manure with litter	29.2	18.0	2.1	--	2.25	1.80	--	--
Poultry manure without litter	32.4	15.2	1.9	29.9	8.8	2.5	1,900	990
Corn, Grain No. 2	9.8	2.2	4.4	1.5	0.02	0.34	3,300	3,854
Soybean meal, solvent extracted, 49%	47.6	4.7	1.5	6.9	1.03	0.70	3,020	2,817
Alfalfa hay, sun-cured, all analyses	17.6	30.1	2.6	9.0	1.53	0.22	2,350	663
Corn silage, all analyses	7.0	25.5	2.8	5.3	0.35	0.28	2,470	--

SECTION 2

CONCLUSIONS AND RECOMMENDATIONS

CONCLUSIONS

1. Reported values for the nutrient content of dried poultry waste (DPW), broiler litter, and dairy cow and beef cattle manures are highly variable. Care should be taken in the use of "average" values when estimating the nutritive value of manures as feedstuffs or for other purposes.
2. When animal manures (DPW, broiler litter, dairy cow and beef cattle manures) are utilized as a feedstuff, they appear most comparable to corn silage and forages such as alfalfa, timothy, and bermudagrass hays and not to energy or protein feeds. The economic value of manures, when used to replace corn silage, appears to be about $58 per tonne, based on their nutrient characteristics (dry matter basis). When hays are replaced, the value of manures as feedstuffs is about $70 per tonne (dry matter basis).
3. DPW used as a feedstuff for laying hens is best described as a source of minerals and some amino acids and has an estimated economic value of about $117 per tonne, dry matter basis.
4. The performance of animals fed animal manures as feedstuffs can, in general, be predicted from the nutrient characteristics of the total diet or ration.
5. Utilization of animal manures as feedstuffs is generally most effective when manures constitute a relatively small fraction, typically less than 20% of the ration.
6. The use of DPW as a feedstuff for both laying hens and ruminants generally enhances animal performance when incorporated into rations at low levels (5-12.5%). Based upon animal performance, the economic value of DPW as a feedstuff is greater than the value estimated from the nutrient composition and fertilizer content.
7. The use of broiler litter as a ruminant feedstuff typically enhances animal performance. The level of utilization that will maximize animal performance varies with the nature of litter management prior to utilization. Estimates of the economic value of broiler litter, based upon animal performance and nutrient composition, are

comparable and exceed the fertilizer value.

8. The use of beef cattle manure as a ruminant feedstuff generally impairs animal performance. The economic value of beef cattle manure as a feedstuff is typically less than its fertilizer value.

9. The utilization of processed animal manures (aerobically digested manure, manure screenings, and Cereco products) as a feedstuff may have merit. Further investigation is, however, necessary before the nutritive value of these materials as a feedstuff can be established.

10. The potential environmental quality benefits derived from the utilization of animal manures as feedstuffs will not be large due to the limited quantities that can be effectively utilized in this manner.

RECOMMENDATIONS

1. Background information, such as the composition of the diet or ration fed and the age, health, and productive state of animals involved, always should be identified when nutrient characteristics of animal manures are reported. The lack of this information hampers an evaluation of the relevance of the reported characteristics and a comparison to other data.

2. The nutrient characteristics of the actual animal manures to be used as feedstuffs should be obtained before the manures are utilized in both experimental and commercial situations. These characteristics should be included in all reports of feeding trials and large scale use of manures as feedstuffs.

3. Rations containing animal manures should be formulated to meet protein needs using digestible protein for ruminants and amino acids for monogastrics. The formulation of rations using crude protein does not reflect the availability of fecal nitrogen.

4. Feeding trials should compare the performance of manure-fed animals to a normal, healthy control group receiving a nutritionally balanced ration. Use of nonrepresentative control groups can result in erroneous and nonusable data.

5. Broiler litter appears to have significant nutritive and economic value as a feedstuff for ruminants.

6. Further studies to more clearly delineate the nutritive and economic values of aerobically digested manures and dairy cow and beef cattle manure screenings are needed.

7. Before results from experimental or other studies on the use of animal manures as feedstuffs are accepted, information on: (1) the adequacy of positive control diets or rations to satisfy nutritional

needs, and (2) the performance of control animals in comparison to established norms must be available and critically analyzed.

SECTION 3

OBJECTIVES AND SCOPE

Although the use of animal manures as feedstuffs appears attractive, the realization of potential benefits remains elusive, and a comprehensive analysis of information to identify the better opportunities for this option has been lacking. The objectives of this report are to: (1) examine various methods of utilizing animal manures as feedstuffs, such as dried manure to livestock and poultry, ensiled manure to livestock, aerobically digested manure to poultry, etc.; (2) assess the economic incentive for the utilization of animal manures as feedstuffs, such as reduced feed costs, increased egg sale revenue, increased animal selling price, etc.; and(3) identify the pollutional control benefits associated with the use of animal manures as feedstuffs, such as decreased potential for air and water pollution, alleviating waste management problems, etc.

This study assembled, critically reviewed and analyzed reported information pertaining to the nutrient characteristics of animal manures and their utilization as feedstuffs. The evaluation focused on dairy cattle, beef cattle, and caged laying hen manures, and broiler litter utilized as a feedstuff for cattle and poultry. These types received emphasis because they represent approximately 85% of the economically recoverable manure produced annually in the United States (Van Dyne and Gilbertson, 1978). Although sheep commonly are used as a recipient species, studies of feeding manure to sheep were not analyzed. Sheep have the ability to efficiently utilize feedstuffs having low economic value. Since the cost of conventional feedstuffs, principally forages, for sheep are low, the gross value of manures as substitutes will be correspondingly low. The results from digestibility trials utilizing sheep as the recipient species, however, were included in this report.

The economic incentive was determined by: 1) the assessment of animal performance from published information on feeding trials and 2) the determination of economic benefits (such as reduced feed efficiency costs, increased animal selling prices, and increased revenue from egg sales).

Two general types of manures were evaluated as sources of animal nutrients: 1) manure which was dried, composted, ensiled, screened or Cereco processed, and 2) liquid manure which was aerobically or anaerobically digested.

The report objectives were achieved by the following methodology:

1. Assessment of the reported nutrient characteristics of animal manures to determine if they could be classified as a protein, energy or forage substitute;
2. Estimation of the economic value of animal manures based on nutrient characteristics;
3. Assessment of animal manures as feedstuffs based upon reported animal performance in feeding trials;
4. Estimation of the economic value of animal manures based on reported animal performance in feeding trials;
5. Identification of the more appropriate types of animal manures that can be used as feedstuffs; and
6. Evaluation of the pollution control benefits that result from the use of manures as feedstuffs.

SECTION 4

FUNDAMENTAL NUTRITIONAL CONCEPTS AND TERMINOLOGY

INTRODUCTION

In this study, emphasis is placed on nutritional considerations as the basis for assessing the technical feasibility of utilizing manures as feedstuffs. To facilitate a better understanding of the subsequent sections, this section briefly presents basic nutritional concepts, methodology, and terminology.

Feedstuffs represent sources of nutrients and energy which when released by digestive processes are absorbed into body fluids and tissues. Nutrients include amino acids or precursors for amino acid synthesis, minerals, and vitamins. Undigested and indigestible residues from feed and metabolic and endogenous losses are concentrated in the excreta. The extent to which these residues can be used as nutrients depends on their biodegradability.

Nutrients absorbed from digested feeds are used for different body processes. Exact utilization depends on animal species, age, and productivity. Total nutrient requirements can be partitioned into maintenance, production, and reproduction. Maintenance requirements refer to the base level of nutrient intake necessary for basal metabolism and normal activity. Nutrients in excess of maintenance requirements are considered production requirements and are utilized for growth, fattening, or production of milk and eggs. Reproduction requirements refer to nutrients utilized for fetus development.

Nutritional requirements of domestic animal species for maintenance, production and reproduction have been established by the National Research Council. A nutritionally balanced ration is a feedstuff or a combination of feedstuffs which meet the physiological requirements for production and/or maintenance. Animal performance will correlate directly with the level of nutrient intake. Productive performance of animals fed a maintenance level diet can be expected to be negligible.

QUALITATIVE NUTRITIONAL REQUIREMENTS

Energy

Available energy is one of the most important characteristics of a feedstuff. Animals obtain energy from the oxidation of dietary carbon and hydrogen sources resulting in the production of carbon dioxide and water. The released energy is used for work, is converted to heat, or is stored in body tissue. Many organic compounds including proteins can serve as dietary sources of energy, but the primary sources are carbohydrates and fats. Not all organic compounds are digestible and only the digestible fraction of a feedstuff can serve as a source of energy and other nutrients. Both feed consumption and efficiency of feed conversion are closely related to the metabolizable energy content of a ration in such animals as the chicken which tends to eat to satisfy energy requirements and adjusts feed intake accordingly.

Amino Acids

Amino acids and precursors for amino acid synthesis long have been recognized as dietary essentials. Amino acids constitute the building blocks for protein synthesis, and proteins are the principal constituents of animal tissue, such as muscle, cartilage, connective tissue, blood proteins, nucleoproteins, hormones, and enzymes. Essential amino acids are those that cannot be synthesized by the animal and must be supplied by the diet. Amino acids which can be synthesized from nonprotein nitrogen compounds are **described** as nonessential amino acids.

Essential amino acid requirements vary by species and for different functions, such as maintenance versus production, within species. The designations of essential and nonessential amino acids apply only to monogastric species. For ruminants, nonprotein nitrogen compounds such as urea can be utilized to provide essential amino acids via microbial synthesis. Essential amino acids for poultry and swine which must be supplied in the diet include arginine, lysine, histidine, leucine, isoleucine, valine, methionine, threonine, tryptophan, and phenylalanine (Scott *et al.*, 1976; Ensminger and Olentine, 1978).

Minerals and Vitamins

Several inorganic elements are required for the metabolic functions of all animals. Minerals are required for skeletal formation, as components of hormones, as activators of enzymes, and for maintenance of osmotic relationships. Essential minerals include calcium, phosphorus, sodium, potassium, selenium, molybdenum, chlorine, magnesium, iron, sulfur, iodine, manganese, copper, cobalt, and zinc. Requirements for minerals vary extensively with species and are dependent upon factors such as sex and age.

Vitamins function as organic catalysts of metabolic reactions. Some vitamins are metabolic essentials but not dietary essentials since they can be synthesized by microorganisms in the digestive tract. This phenomenon is species dependent. Vitamins are fat soluble (vitamins A, D, E, and K) or water soluble (B-complex vitamins and vitamin C). Although feedstuffs are important sources of vitamins and minerals, supplements commonly are used to assure a balanced ration.

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Nutrient Value of Feedstuffs

The value of a material as a feed is dependent on its ability to supply nutrients required for maintenance, production, and reproduction. Determination of the diet nutrient composition and the respective availability of the nutrients are essential to the scientific formulation of practical diets to meet established nutritional requirements. The following outlines the principal methods of feedstuff nutrient characterization and discusses the significance of the various parameters.

Proximate Analysis

The proximate analysis or Weende Food Analysis Scheme (Crampton and Lloyd, 1959) has been the most widely utilized procedure for estimating the nutritive value of feedstuffs. This procedure consists of fractionating feed materials into six components: moisture, ash, crude protein, ether extract, crude fiber, and nitrogen-free extract. Procedures and major components are outlined in Table 2.

TABLE 2. FRACTIONS OF PROXIMATE ANALYSIS

Fraction	Procedure	Major Components
1. Moisture (dry matter)	Heat sample at 100°C to a constant weight	Water and any volatile compounds
2. Ash	Ignite sample at 600°C for 2 hr	Mineral elements
3. Crude protein (TKN x 6.25 = crude protein)	Kjeldahl sulfuric-acid digestion	Proteins, amino acids, nonprotein nitrogen
4. Ether extract (fat)	Extraction with ether	Fats, oils, waxes, resins, pigments
5. Crude fiber (CF)	Residue after boiling in weak acid and weak alkali	Cellulose, hemicellulose, lignin
6. Nitrogen-free extract (NFE)	Remainder - 100 minus sum of other factors	Starch, sugars, some cellulose, hemicellulose, and lignin

The ash fraction represents an estimate of the inorganic or total mineral content of a feedstuff and is used to indicate possible total mineral deficiency or excessive mineral content. Excessive mineral content can adversely affect digestive processes in some species. The ash determination is not capable of indicating deficiencies of specific minerals.

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The crude protein estimation is based on the total Kjeldahl nitrogen (TKN) determination and the assumption that the average nitrogen content of protein is 16%. This results in the multiplication factor of 6.25 used to convert TKN to crude protein. Crude protein includes both protein nitrogen and nonprotein nitrogen and is of limited value in assessing the value of a feedstuff as a protein source for monogastric animals. While crude protein is of greater value in ruminant nutrition, this analysis does not estimate the digestibility of nonprotein nitrogen compounds such as amines, purines, pyrimidines, urea, and ammonia.

Ether extract is only an approximation of the fat content of a feedstuff in that it includes anything that can be extracted with ether, such as organic acids, oils, pigments, alcohol, and fat-soluble vitamins. Many complex lipids, such as phospholipids and fats bound to proteins, are not completely extracted.

Crude fiber represents an attempt to estimate indigestible feedstuff carbohydrates. It is based on the assumption that those carbohydrates which are dissolved by boiling in dilute acid and then in dilute alkali will also be readily digestible by animals. The term crude fiber represents about 80% of the cellulose, and only about 15% of the hemicellulose and lignin in a sample. It is not an accurate measurement of indigestible materials. Ruminants and herbivorous nonruminants can utilize a large portion of the cellulose component of crude fiber.

Nitrogen-free extract (NFE) is a calculated estimate of digestible carbohydrates and is a catchall for organic materials for which there are no specific analyses in the proximate analysis procedure. NFE is calculated as follows:

$$\begin{aligned}\text{NFE, \%} = 100 - (&\text{moisture, \%} + \text{crude fiber, \%} + \text{ash, \%} + \\ &\text{ether extract, \%} + \text{crude protein, \%})\end{aligned} \tag{1}$$

The NFE component of manure is to a large degree a mathematical fiction since it is based on the crude protein factor of 6.25, which grossly underestimates the organic contribution of microbial metabolic wastes that are the dominant nonfibrous component of feces (Van Soest, 1980). Also, the inherent errors of the crude fiber analysis are carried over in the calculation of NFE.

Energy

Several parameters characterize energy values of feedstuffs such as total digestible nutrients (TDN), apparent digestible energy (ADE), metabolizable energy (ME), and net energy (NE). TDN is an estimate of the energy value of a feedstuff based on feeding trial results in which the proximate analysis parameters for the feedstuff and feces are compared to determine the digestible fraction. TDN is computed by (Ensminger and Olentine, 1978):

$$\text{TDN, \%} = \frac{\text{DCP} + \text{DCF} + \text{DNFE} + (\text{DEE} \times 2.25)}{\text{Feed Consumed, kg}} \times 100 \tag{2}$$

where: DCP = digestible crude protein, kg
DCF = digestible crude fiber, kg
DNFE = digestible nitrogen-free extract, kg
DEE = digestible ether extract, kg

Digestible ether extract is multiplied by 2.25 to reflect the higher energy content of fats. Digestible ether extract is likely to be a large error in fecal analysis since most microbial fatty acids are excreted as soaps of calcium and magnesium which are ether insoluble, unless pH adjustments are made.

Digestible energy (DE) can be approximated by multiplying the kilograms of TDN in a material by 4400 kcal. TDN represents a poor approximation of the energy value of feedstuffs for several reasons. First, only digestive losses are considered. Energy contained in urine, gaseous products, and heat is not included. Second, there is a poor relationship between crude fiber and NFE digestibility in certain feeds. Third, energy values of roughages are overestimated in relation to concentrates due to higher heat losses per unit mass of TDN in high fiber feedstuffs (Ensminger and Olentine, 1978; Maynard and Loosli, 1969). Thus, TDN is of questionable value as a measure of feedstuff energy.

Energy balance feeding trials provide a more accurate estimation of feedstuff energy content by partitioning the gross energy content as shown in Figure 1. Values for gross energy as well as those for fecal and urinary energy are determined by bomb calorimetry (Maynard and Loosli, 1969). Direct or indirect calorimetry is used to determine the heat increment which includes heat of fermentation and heat of nutrient metabolism. Apparent digestible energy, metabolizable energy, and net energy can be mathematically described as follows:

$$\text{Apparent Digestible Energy} = \text{Gross Energy} - \text{Fecal Energy} \tag{3}$$

$$\text{Metabolizable Energy} = \text{Apparent Digestible Energy} - (\text{Urinary Energy} + \text{Energy in Gaseous Products}) \tag{4}$$

$$\text{Net Energy} = \text{Metabolizable Energy} - \text{Heat Increment} \tag{5}$$

Apparent digestible energy (ADE) is utilized widely due to its relative ease of determination. It is roughly comparable to TDN in that energy lost as urine, gaseous products, and heat is not considered. ADE is not applicable to feedstuffs for poultry in that fecal material and urine are not excreted separately. The inclusion of the heat increment in the ME determination results in the overestimation of the energy value of roughages, as compared to concentrates, which is also true of the TDN estimation. ME is considered to be the most accurate estimate of the energy value of feedstuffs for poultry, but not for ruminants. Due to the inclusion of the heat increment in metabolizable energy values, net energy (NE) is of greater accuracy to estimate the energy value of feedstuffs for ruminants.

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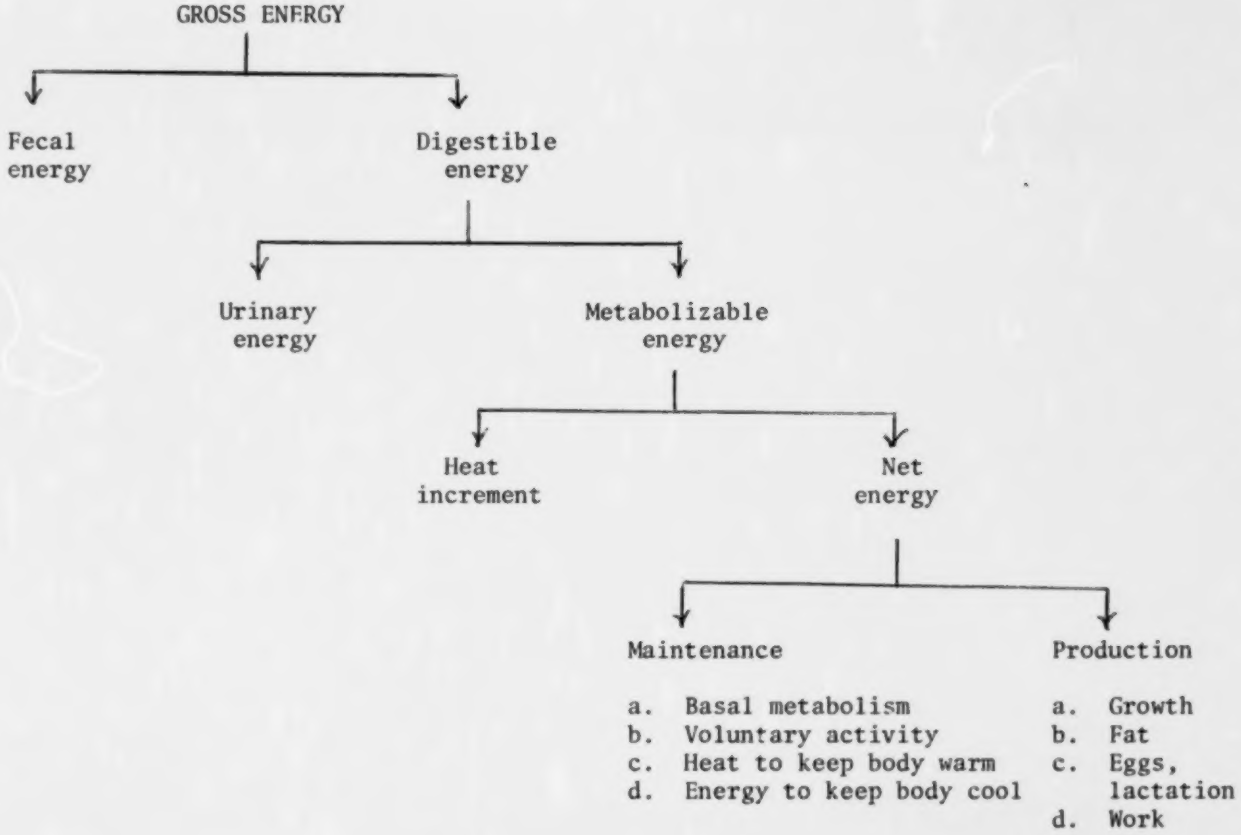
GROSS ENERGY
Fecal energy
Digestible energy
Urinary energy
Metabolizable energy
Heat increment
Net energy
Maintenance
a. Basal metabolism
b. Voluntary activity
c. Heat to keep body warm
d. Energy to keep body cool
Production
a. Growth
b. Fat
c. Eggs, lactation
d. Work

Figure 1. Relationships Between Different Forms of Energy Consumed as Feedstuffs

Protein

Although crude protein is used extensively in the formulation of rations or diets, recognition of the limitations of this estimate has resulted in the adoption of alternatives such as digestible protein (DP), total true protein (TP), and amino acid composition.

Digestible protein represents a calculated estimate of the digestible fraction of crude protein utilizing regression equations developed from reported data (Harris, 1970). These equations are specific for both species and type of feed. Digestible protein is most commonly used in relation to feedstuffs for ruminants. Reported values also are available for feedstuffs for swine.

Total true protein represents a more accurate estimate of the protein value of feedstuffs for monogastric species. The limitation of TP is that amino acid composition is not delineated. Thus, a feedstuff may be adequate with respect to TP but be deficient in one or more essential amino acids. Amino acid composition represents the most fundamentally sound basis of assessing the protein value of feedstuffs for monogastric species and can be determined by calorimetric techniques or by gas-liquid chromatography.

Forage Fiber Analysis

Limitations of the proximate analysis method have resulted in a more accurate method (Goering and Van Soest, 1970) of estimating digestible and indigestible fractions of feedstuffs. Using the forage fiber analytical methodology, a feedstuff is separated into four fractions: neutral detergent solubles, neutral detergent fiber (NDF), acid detergent fiber (ADF), and lignin.

In the first step, the feed sample is boiled in a neutral detergent solution to separate the soluble and insoluble fractions. The soluble fraction is comprised of cell contents and includes sugars, starches, pectins, proteins, lipids, nonprotein nitrogen, and water soluble minerals and vitamins. This fraction is highly digestible (approximately 98%) by both ruminants and nonruminants. The insoluble fraction, NDF, consists of cell walls, cellulose, hemicellulose, silica, fiber-bound protein, and lignin. The digestibility of the NDF fraction of a feedstuff is dependent on microbial activity in the digestive tract, and NDF is essentially indigestible by nonruminants. Feedstuffs having high NDF fractions generally produce lower feed intake and reduced levels of performance when fed to ruminants.

Boiling the NDF fraction in an acid detergent solution solubilizes hemicellulose. The remaining insoluble fraction, termed ADF, contains cellulose, lignin, and some acid insoluble ash (silica). Cellulose is highly digestible by ruminants, but both lignin and silica are indigestible. ADF can serve as an indicator of digestible dry matter and digestible energy.

The cellulose and lignin components of ADF can be separated by the addition of sulfuric acid to solubilize cellulose or potassium permanganate to remove cellulose. Lignin is estimated after ignition of the insoluble fraction to determine acid insoluble ash. Lignin is essentially indigestible by all animals and limits availability of cellulose to rumen bacteria.

The cellulose and hemicellulose fractions of a feedstuff can be calculated from NDF, ADF, and lignin values as follows:

$$\text{Hemicellulose} = \text{neutral detergent fiber} - \text{acid detergent fiber} \tag{6}$$

$$\text{Cellulose} = \text{acid detergent fiber} - \text{lignin} \tag{7}$$

Although the forage fiber analytical methodology was developed to evaluate forages, it has been applied to other materials including human foods, animal manures, and other products (Van Soest and Robertson, 1976).

Species Utilization

The ability of an animal to transform, digest, and utilize feedstuffs depends upon its organs of digestion. Table 3 summarizes the digestive system of various species. Because of the difference in the digestive systems, the nutritional characteristics of feedstuffs and their utilization are species-dependent.

TABLE 3. THE DIGESTIVE SYSTEMS OF VARIOUS SPECIES

Species	Digestive System
Man, dog, carnivorous animals	Esophagus, stomach, small intestine, large intestine
Pig, omnivorous animals	Cecum, stomach, small intestine, large intestine
Ruminants	Forestomach, rumen, reticulum, omasum, large intestine, small intestine, cecum
Poultry	Esophagus, crop, proventriculus, gizzard, small intestine.

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SECTION 5

NUTRIENT CHARACTERISTICS OF POULTRY MANURE, BROILER LITTER, AND DAIRY COW AND BEEF CATTLE MANURE

INTRODUCTION

This section evaluates the available information on the nutrient characteristics of poultry manure, broiler litter and cattle manure. These potential feedstuffs are characterized in terms of their mineral, amino acid, protein, and other nutrient parameters.

These characteristics are then compared on a nutrient and economic basis to conventional feedstuffs so as to identify the potential of broiler litter and poultry and cattle manure as animal feedstuffs. The conventional feedstuffs used for comparison are corn silage, timothy hay, alfalfa hay, bermudagrass hay, soybean meal, cottonseed meal, grain corn and sorghum grain. These feedstuffs are common ingredients in animal feeds and are the ones for which manures and litter are most commonly substituted in feeding trials. The nutrient characteristics of these conventional feedstuffs are presented in Appendix B.

Subsequent sections evaluate the nutrient characteristics of other processed manures (Section 6) and identify the value of the potential feedstuffs on the basis of results from feeding trials (Sections 7 through 10).

DRIED POULTRY WASTE

This section discusses the nutrient characteristics of dried poultry waste (DPW) from caged laying hens. DPW is composed of freshly collected feces from commercial laying or broiler flocks not receiving medicants. It is thermally dehydrated to a moisture content of not more than 15%, does not contain any substances at harmful levels, is free of extraneous materials such as wire, glass and nails, and is labeled to show the minimum percent protein and fat and percent fiber. It may be used in sheep, lamb, beef, and dairy cattle and broiler and layer chick feeds with broiler and laying rations usually limited to 20% and 30%, respectively (Essig, 1977).

The nutrient characteristics of DPW are highly variable and can be a result of differences in formulation of poultry diets, methods of handling and treatment of the wet feces, and the drying procedure utilized. Evans et al. (1978) reported that when a high and low crude protein diet (17.8% versus 14.2%) was fed to laying hens, significant differences were observed in fecal composition. Nitrogen and nitrogenous compounds in the feces of

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the 17.8% crude protein group were higher than the 14.2% crude protein group. The drying process can cause protein losses ranging from 3 to 40%. Bird age will affect fecal output, although the influence on raw waste composition is minimal.

The nutrient, mineral and amino acid compositions of DPW are shown in Tables 4, 5, and 6. Protein digestibility of the crude protein in DPW has been reported to be 53% for laying hens (Yoshida and Hoshii, 1963) and 57% for ruminants (Lowman and Knight, 1970; Bull and Reid, 1971; Oltjen et al., 1972; Tinnimit et al., 1972; Van Soest and Robertson, 1976).

DPW has been erroneously classified as a "bulky protein concentrate" on the basis of its crude protein and crude fiber levels (Bhattacharya and Taylor, 1975). By definition, concentrates are feeds that are high in NFE and TDN and low in crude fiber (Ensminger and Olentine, 1978). The nutrient characteristics of DPW shown in Table 4 do not fulfill this definition and it is not appropriate to classify DPW as a "protein concentrate".

The extreme ranges in metabolizable energy (ME) values confound the utilization of DPW as an energy source. While the ME of DPW is too low to be incorporated at high levels in efficient poultry rations, it is comparable to hay fed to ruminants (Bhattacharya and Taylor, 1975). Based upon its ADF, NDF and lignin content, DPW is comparable to forages when fed to ruminants (Van Soest and Robertson, 1976).

The mineral composition of DPW (Table 5) reveals that the total ash content is high and can restrict its value as a feedstuff when used in large quantities. Soluble ash may adversely affect rumen microorganisms and food passage rates in ruminants (Van Soest, 1980). When DPW is utilized as a mineral source, the absorption and digestibility of calcium and phosphorus has been reported to be high when fed to ruminants (Bull and Reid, 1971). However, the utilization of calcium and phosphorus in DPW by laying hens is decreased when compared to conventional mineral supplements (Polin et al., 1971).

BROILER LITTER

Broiler litter consists of bedding material, excreta, wasted feed and feathers. Bedding usually is a low cost by-product such as wood shavings, peanut hulls, corn cobs, grass hay or straw. The characteristics of broiler litter are highly variable, with the variation possibly caused by storage time of the litter prior to usage, number of batches of broilers raised on the litter, mechanical or chemical treatment of the litter prior to analysis, type of bedding utilized, and the composition of the diet fed to the broilers. A significant loss of nutrients occurs if the litter is stored for considerable periods of time (Cross, 1977). The litter characteristics also are influenced by the method of handling and treatment, with the drying process causing a 20% reduction in nitrogen (Fontenot, et al., 1971).

The nutrient, mineral and amino acid compositions of broiler litter are shown in Tables 7, 8, and 9. The digestible protein and crude fiber

TABLE 4. NUTRIENT CHARACTERISTICS OF DPW

Composition of Dry Matter, %	Mean	Range	Number of Observations	Source*
Crude Protein	28.0	17.0 - 40.4	25	1,2,3,5,6,7,10, 12,13,14,15,16, 18,20,21,24,27
True Protein	14.6	11.3 - 21.8	5	7,14,20,21,27
Digestible Protein (Ruminant)	12.6	9.7 - 14.6	5	8,14,23,25
NPN x 6.25	9.7	7.8 - 11.6	2	7,21
Ether Extract	2.2	1.4 - 3.2	21	3,5,7,10,11,13, 14,15,16,18,20, 21,22,24,27
Crude Fiber	13.0	8.2 - 21.0	20	5,6,7,10,11,13, 15,16,18,20,21, 22,24,27
NFE	33.4	21.8 - 45.1	11	6,7,11,14,15,16 22,24
TDN	52.3	-	1	14
ADF	24.7	14.0 - 43.1	5	2,19,26
NDF	52.4	37.7 - 62.0	3	2,19
Lignin	1.4	-	1	26
Energy, kcal/kg				
Gross energy	3047	2200 - 3522	13	3,5,10,16,17, 18,21
Digestible Energy (Ruminant)	2456	1875 - 3194	3	3,8,9
Metabolizable Energy				
(Poultry)	1309	480 - 2050	11	1,13,16,17,21,27
(Ruminant)	1900	-	1	8
Dry Matter, %	84.7	78.7 - 89.7	5	3,5,12,15,20

*See Appendix A

TABLE 5. MINERAL COMPOSITION OF DPW

Composition of Dry Matter, %	Mean	Range	Number of Observations	Source*
Ash	27.6	13.4-42.9	22	3,5,6,7,10,11,13,14,15,16,18,20,21,22,24,27
Aluminum	0.11	.07-.20	3	6,7
Calcium	8.07	5.5-12.3	20	3,4,6,7,9,10,13,14,15,16,27
Chlorides	0.87	.65-1.08	4	4,6,13
Iron	0.54	.15-1.22	11	4,6,7,15,24
Magnesium	0.50	.20-.77	8	4,6,7,15,18
Phosphorus	2.29	1.34-2.64	16	3,4,6,7,9,10,13,15,16,24,27
Potassium	2.24	1.72-3.30	6	4,6,7,15,24
Sodium	0.60	.26-.96	5	4,6,7,15
ppm				
Arsenic	1.5	.66-2.34	2	6,16
Cadmium	0.94	.58-1.30	2	6
Chromium	4.9	-	1	6
Copper	66	18-179	11	4,6,7,13,15,16,18
Lead	4.6	3.45-5.8	2	6
Manganese	320	233-468	11	4,6,7,13,15,18
Mercury	<0.04	-	1	6
Selenium	0.68	.47-.90	2	6,16
Zinc	376	141-713	11	4,6,7,13,15,18

* See appendix A

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TABLE 6. AMINO ACID COMPOSITION OF DPW

Amino Acid, % of dry matter	Mean	Range	Number of Observations	Source*
Arginine †	0.39	.35-.47	5	13,16,17
Cystine	.06	.02-.14	3	13,17
Glycine	1.65	.51-2.43	5	13,16,17
Histidine †	.20	.18-.21	5	13,16,17
Leucine †	.64	.55-.77	5	13,16,17
Isoleucine †	.40	.33-.51	5	13,16,17
Lysine †	.41	.33-.45	5	13,16,17
Methionine †	.16	.10-.33	5	13,16,17
Phenylalanine †	.38	.32-.45	4	13,16,17
Tyrosine	.31	.27-.37	4	13,16,17
Valine †	.52	.47-.60	5	13,16,17
Alanine	.67	.66-.67	2	16,17
Proline	.58	.51-.64	2	16,17
Glutamic Acid	1.33	1.32-1.33	2	16,17
Serine	.52	.51-.53	2	16,17
Threonine†	.45	.40-.48	3	16,17
Aspartic Acid	1.03	1.02-1.03	2	16,17
Tryptophan †	.53	-	1	16
Total Amino Acids	10.23			
Essential Amino Acids	3.63			
% of Total	35.5			

*See appendix A
†Essential amino acids

TABLE 7. NUTRIENT CHARACTERISTICS OF BROILER LITTER

Composition of Dry Matter, %	Mean	Range	Number of Observations	Source*
Crude Protein	26.8	14.4-40.0	28	1,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17,18,19,20,21,23
True Protein	15.8	13.6-18.0	7	3,4,7,12,14
Digestible Protein (Ruminant)	22.6	21.6-23.4	6	4,14,22
NPN x 6.25	7.6	4.8-15.1	11	5,9,12,15,16,21
Ammonia x 6.25	5.1	4.2-6.4	5	3,4,15,18
Ether Extract	2.4	0.8-3.5	19	1,3,4,5,7,8,9,10,11,12,13,14,15,18,19,20
Crude Fiber	21.2	11.4-32.2	25	1,3,4,5,7,10,11,12,13,14,15,16,17,18,19,20,21
NFE	27.5	10.5-34.0	15	3,4,5,7,8,9,10,11,12,14,15,18,19
TDN	58.9	52.0-72.5	5	14,16,17,19,21
ADF	30.4	-	1	24
NDF	47.4	44.0-56.4	5	8,9
Lignin	9.7	9.4-10.4	3	3,4
Energy, Kcal/kg				
Gross Energy	3652	3250-3862	5	4,5,13,15
Digestible Energy (Ruminant)	2440	-	1	14
Metabolizable Energy (Ruminant)	1627	1100-2181	3	14,20
Dry Matter, %	80.6	72.7-89.1	19	3,4,5,7,8,12,14,15,16,19,21

*See appendix A

TABLE 8. MINERAL COMPOSITION OF BROILER LITTER

Composition of Dry Matter, %	Mean	Range	Number of Observations	Source*
Ash	18.6	9.5-30.7	26	1,3,4,5,7,8,9,10,11,12,13,14,15,17,18,19,20,21
Aluminum	0.05	.03-.09	3	6,15
Calcium	2.60	1.60-6.07	20	3,4,5,6,8,9,12,14,15,16,19,21,23
Chlorides	0.35	-	1	6
Iron	0.07	.05-.08	4	6,12
Magnesium	0.39	.26-.54	13	6,12,14,15,21,23
Phosphorus	1.81	.89-2.86	18	3,4,5,6,8,9,12,14,15,19,21,23
Potassium	1.78	1.54-1.88	9	6,12,21,23
Sodium	0.38	.21-.54	2	6,12
Sulfur	0.24	.17-.45	7	21,22
ppm				
Arsenic	4.1	.6-11.0	8	6,12,21
Cadmium	0.86	.42-1.3	2	6
Chromium	6	-	1	6
Copper	50	31-127	9	6,12,21,23
Lead	2.3	2.1-2.5	2	6
Manganese	211	166-321	5	6,12,23
Mercury	0.06	-	1	6
Selenium	0.44	.38-.50	2	6
Zinc	187	133-272	5	6,12,23

*See appendix A

TABLE 9. AMINO ACID COMPOSITION OF BROILER LITTER

Amino Acid, % of dry matter	Mean	Range	Number of Observations*
Arginine †	0.84	.50-1.42	5
Cystine	.22	.09-.47	5
Glycine	2.12	1.37-2.98	5
Histidine †	.29	.24-.43	5
Leucine †	1.11	1.00-1.23	5
Isoleucine †	.64	.59-.68	5
Lysine †	.69	.57-.93	5
Methionine †	.30	.13-.62	5
Phenylalanine †	.64	.54-.80	5
Tyrosine	.48	.33-.73	5
Valine †	.88	.76-1.10	5
Alanine	.94	.88-1.09	5
Proline	1.34	.92-2.26	5
Glutamic Acid	2.66	2.02-4.06	5
Serine	.76	.57-1.15	5
Threonine †	.67	.57-.80	5
Aspartic Acid	1.27	.99-1.50	5
Tryptophan †	-	-	-
Total Amino Acids	15.85		
Essential Amino Acids	5.39		
% of Total	34.0		

*Bhargava and O'Neil (1975) and Bhattacharya and Fontenot (1965, 1966)

†Essential Amino Acids

levels of broiler litter are greater than that of DPW. Protein digestibility has been reported not to be influenced by bedding material types (Bhattacharya and Fontenot, 1966), although analysis of various bedding materials has indicated significant differences in their digestibilities (Van Soest and Robertson, 1976).

The mineral composition of broiler litter (Table 8) indicates that it is a good source of calcium and phosphorus, although it has less than DPW. These minerals can reduce the amount of supplemental mineral sources needed in ruminant rations (Fontenot, 1977).

The amino acid composition of broiler litter (Table 9) constitutes approximately 59% of the crude protein. The digestibility of the crude protein appears relatively high, over 80%, but decreases as the bedding content increases (Bhattacharya and Fontenot, 1965).

DAIRY COW MANURE

Dairy cow manure consists of feces, urine and, in many instances, bedding from lactating or nonlactating cows. The cows are usually fed a ration high in roughage with supplemental grain sometimes provided. The composition of dairy cow manure is influenced by: (1) the type and quantity of bedding included with the manure, (2) whether urine is included with the manure, (3) the feed ration composition, and (4) the type of animal (lactating, nonlactating, calf, etc.). The manure from dairy cows receiving a high roughage ration had a reduced nutritive value (Fisher, 1974; Van Soest and Robertson, 1976).

The nutrient, mineral and amino acid compositions of dairy cow manure are shown in Tables 10, 11, and 12. Crude and true protein levels are lower than DPW, and digestible protein is lower than both DPW and conventional feedstuffs. Crude fiber, ADF, NDF and lignin levels are higher than DPW and conventional energy and protein feedstuffs. The dry matter digesibility of dairy cow manure has been reported to be 48% or lower. Differences in reported data might be attributed to the ration the cows were fed and to changes in storage prior to the manure being incorporated in a feed. Van Soest and Robertson (1976) reported a higher digestibility for cow manure from animals fed a corn-hay ration than those fed an alfalfa ration.

The amino acid composition of dairy cow manure (Table 12) was obtained from animals receiving a ration composed of: 55% haylage-corn silage, 15% corn and cob meal, 24% brewers' grain, and 3% soybean meal. The crude protein of the ration was 16.2% and the calculated amino acid content was 7.8%. The amino acid/crude protein ratio of the manure is the highest of any animal manure evaluated.

The mineral composition of dairy cow manure (Table 11) indicates it is higher in calcium, phosphorus and potassium than conventional feedstuffs. However, the absorption and digestibility of these minerals has not been reported.

TABLE 10. NUTRIENT CHARACTERISTICS OF DAIRY COW MANURE

Composition of Dry Matter, %	Mean	Range	Number of Observations	Source*
Crude Protein	15.3	12.0-21.9	19	1,5,6,7,8, 10,13,14
True Protein	12.5	-	1	5
Digestible Protein (Ruminant)	5.1	3.2-7.3	3	9,11,12
Ammonia x 6.25	4.8	4.1-6.1	6	6,7
Ether Extract	3.0	2.5-3.8	5	1,5,10
Crude Fiber	29.8	23.5-37.5	3	5,10,14
NFE	35.2	29.4-41.0	2	5,10
TDN	45.0	-	1	5
ADF	43.7	33.6-55.7	5	8,12
NDF	66.0	58.4-71.0	8	5,8,13
Lignin	14.4	7.2-27.1	6	5,8,13
Energy Kcal/kg				
Gross Energy	3674	2500-4955	10	1,2,4
Metabolizable Energy (Ruminant)	1208	-	1	14
Dry Matter, %	15.5	10.9-20.7	8	2,3,4,5,7

*See appendix A.

TABLE 11. MINERAL COMPOSITION OF DAIRY COW MANURE

Composition of Dry Matter, %	Mean	Range	Number of Observations	Source*
Ash	13.4	8.1-16.5	10	1,5,8,10,14
Calcium	3.88	2.3-4.9	6	3,6,14
Chlorides	1.72	1.19-2.20	3	7
Iron	0.27	-	1	3
Magnesium	0.64	.42-1.03	4	3,6
Phosphorus	0.65	.25-1.60	16	1,3,4,6,7, 10,14
Potassium	1.42	.81-1.75	7	6,7,10
Sodium	0.42	.32-.53	6	6,7
ppm				
Copper	72	-	1	3
Manganese	292	-	1	3
Zinc	327	-	1	3

*See appendix A.

TABLE 12. AMINO ACID COMPOSITION OF DAIRY COW MANURE*

Amino Acid	% of Dry Matter
Arginine †	0.45
Glycine	.54
Histidine †	.23
Leucine †	1.07
Isoleucine †	.59
Lysine †	.63
Methionine †	.18
Phenylalanine †	.51
Tyrosine	.41
Valine †	.62
Alanine	.76
Proline	.62
Glutamic Acid	1.46
Serine	.50
Threonine †	.55
Aspartic Acid	1.08
Total Amino Acids	10.20
Essential Amino Acids	4.83
% of Total	47.4

*Unpublished data, J. Chandler (1979).
†Essential amino acids

BEEF CATTLE MANURE

Beef cattle manure is composed of feces, urine and, in some instances bedding. The manure normally is allowed to accumulate for varying time periods prior to removal on different types of strata. One of the major factors that affects the variation in beef cattle manure characteristics is the type of housing from which the manure is collected. The nitrogen content of manure collected from unpaved open lots is about one-half of the content of manure collected from dry lots or total confinement lots with slotted or paved floors (Adriano, 1975). Variation can also be due to: (1) time of year the manure is collected, (2) length of time between excretion and collection, (3) the extent to which bedding is included, and (4) the treatment of the manure prior to analysis and utilization.

The nutrient, mineral and amino acid compositions of beef cattle manure are shown in Tables 13, 14, and 15. The crude protein levels is similar to dairy cow manure, but lower than DPW, and the digestible protein is lower than DPW and conventional energy and protein feedstuffs. Crude fiber, ADF, NDF and lignin levels are comparable to broiler litter, but higher than conventional energy and protein feedstuffs.

The ash content of beef cattle manure is high but is extremely variable due to inclusion of dirt and other foreign matter (Table 14). This contamination can restrict the utilization of beef cattle manure as a feedstuff. The high ash content also can be attributed to the decomposition that will occur if the manure is permitted to accumulate for long periods of time before removal and utilization.

The amino acid composition of beef cattle manure varies (Table 15). This variation can be attributed to the type of ration fed, which affects the degree of rumination and the microbial synthesis of amino acids in the rumen.

The ration the animals are fed influences the nutrient composition of beef cattle manure. Table 16 clearly demonstrates that if beef cattle manure is to be utilized as a feedstuff, manure from steers fed concentrates, high grain or low roughage rations has a higher nutritive value than manure from steers fed all roughage or silage rations.

Ensiling beef cattle manure with low cost roughages has been suggested as a method to increase the nutritive value and digestibility of the manure, destroy harmful microorganisms, and decrease handling costs (Anthony, 1971). Yokoyama and Nummy (1976) ensiled beef cattle manure with corn silage and reported that the nutritive value of the resultant mixture was enhanced. Lamm _et al_. (1977) reported similar results with ensiled cattle manure and legume-grass hay. Composting feedlot manure and incorporating it into high concentrate rations has been reported to improve the apparent digestibility of the manure (Albin and Sherrod, 1975).

Bhattacharya and Taylor (1975) concluded that beef cattle manure has little or no value as a source of energy or protein, even when incorporated at low levels in nonruminant rations. The value of beef cattle manure as

TABLE 13. NUTRIENT CHARACTERISTICS OF BEEF CATTLE MANURE

Composition of Dry Matter, %	Mean	Range	Number of Observations	Source*
Crude Protein	16.5	12.2-27.0	27	1,3,8,9,11, 12,14,16,17, 18,21,22
Digestible Protein (Ruminant)	5.6	3.2-7.4	4	12,15,19
Ether Extract	2.8	1.6-7.4	12	8,9,13, 16,17,18
Crude Fiber	22.6	9.2-31.4	6	9,13,14,16,18
NFE	28.1	14.6-36.5	10	8,19,13,16
TDN	48.5	48-49	2	9,12
ADF	33.1	20.8-51.1	11	5,6,10,11, 14,20
NDF	54.8	31.7-71.8	21	3,5,6,12,14, 20
Lignin	8.6	5.0-15.0	4	11,12,14,20
Energy Kcal/kg				
Gross Energy	3937	2920-4866	9	8,13,14
Digestible Energy (Ruminants)	2160	-	1	9
Metabolizable Energy (Ruminants)	1777	-	1	9
Dry Matter, %	21.1	15.7-25.2	10	1,3,16,17,18

*See appendix A.

TABLE 14. MINERAL COMPOSITION OF BEEF CATTLE MANURE

Composition of Dry Matter, %	Mean	Range	Number of Observations	Source*
Ash	29.2	11.5-47.5	16	8,9,11,12,13, 17,22
Aluminum	0.66	.17-1.56	4	7
Calcium	1.71	.87-3.02	11	1,7,9,12,18, 21,22
Chlorides	0.93	.85-1.01	2	7
Iron	0.33	.16-.65	9	1,7,22
Magnesium	0.47	.38-.63	9	1,7,22
Phosphorus	0.80	.39-1.60	9	1,7,9,12,18, 21,22
Potassium	2.25	1.10-3.00	7	1,7,22
Sodium	0.61	.26-.91	5	1,7,21
ppm				
Arsenic	1.54	.88-2.2	2	7
Cadmium	0.75	.24-1.3	5	7,21
Chromium	25.5	20-31	2	7
Copper	26.8	19.5-40	6	1,7
Lead	5.5	2.1-12.7	5	7,21
Manganese	157	111-222	8	1,7
Mercury	0.04	.03-.05	2	7
Selenium	0.44	.32-.60	4	7
Zinc	112	79.2-150	8	1,7

*See appendix A.

TABLE 15. AMINO ACID COMPOSITION OF BEEF CATTLE MANURE

Amino Acid, % of Dry Matter	Mean	Range	Number of Observations	Source*
Arginine †	0.28	.14-.44	6	2,3,4,
Cystine	.11	.08-.14	4	2
Glycine	.52	.39-.69	5	2,3
Histidine †	.19	.09-.26	6	2,3,4
Leucine †	.47	.44-.53	5	2,4
Isoleucine †	.37	.21-.56	6	2,3,4
Lysine †	.51	.33-.73	6	2,3,4
Methionine †	.15	.06-.23	6	2,3,4
Phenylalanine †	.02	.01-.06	4	2,4
Tyrosine	.02	.01-.04	5	2,3,4
Valine †	.44	.29-.61	6	2,3,4
Alanine	.58	.45-.66	6	2,3,4
Proline	.56	.24-.76	6	2,3,4
Glutamic Acid	1.08	.62-1.47	6	2,3,4
Serine	.31	.15-.46	6	2,3,4
Threonine †	.46	.21-.67	6	2,3,4
Aspartic Acid	.78	.52-1.02	6	2,3,4
Total Amino Acids	6.85			
Essential Amino Acids	2.89			
% of Total	42.2			

* See appendix A

† Essential amino acids

TABLE 16. INFLUENCE OF RATION ON BEEF CATTLE MANURE COMPOSITION AND DIGESTIBILITY

COMPOSITION

Diet	Crude Protein	Ether Extract	Crude Fiber	Ash
	% of Dry Matter			
Low Roughage*	20.69	4.69	15.72	-
High Roughage*	18.04	2.56	20.46	-
Concentrate †	15.8	2.9	17.9	8.5
All Roughage †	10.1	1.2	16.2	35.5
All Roughage, ground †	13.6	1.6	28.9	12.8
High Grain ‡	16.7	-	-	9.1
Silage ‡	13.0	-	-	21.2

DIGESTIBILITY*

Diet	Crude Protein	Ether Extract	Crude Fiber
Low Roughage	49.1	77.3	32.6
High Roughage	32.1	55.8	3.2

* Lucas et al. (1975)
† Braman (1975)
‡ Ward and Muscato (1976)

a feedstuff may lie in its utilization as a forage supplement in ruminant rations.

COMPARISON TO CONVENTIONAL FEEDSTUFFS

Feedstuffs are classified into three major categories: (1) energy feeds, (2) protein feeds, and (3) forages (Ensminger and Olentine, 1978). Energy feeds are defined as those that are high in energy, low in fiber (under 18%) and contain less than 20% protein (corn grain and sorghum grain). Protein feeds are those containing more than 20% digestible or true protein (soybean meal and cottonseed meal). Forages are defined as those feeds that are vegetative material in a fresh, dried or ensiled state which are fed to livestock and average more than 18% fiber in the dry state (corn silage, timothy, alfalfa, and bermudagrass hays).

The nutritive value of manures and broiler litter as feedstuffs can be identified by using the definitions noted above and comparing the average values of digestible protein, ADF, TDN, crude protein, and amino acid content in the previous tables to the average values for conventional feedstuffs (Figures 2, 3, 4, and 5). These comparisons indicate that on the basis of the ratios of digestible protein to ADF, and digestible protein to TDN, animal manures are more comparable to forages than to protein or energy feeds. On the basis of crude or digestible protein and amino acid content, animal manures should not be considered as a protein feed for ruminants or non-ruminants.

Protein feeds are the most expensive feedstuff with the exception of the nutrient phosphorus. From an economic point-of-view, the utilization of animal manures as a protein feed would offer the largest economic incentive. However, the digestible protein levels of DPW, dairy cow and beef cattle manure are below 20%, and they therefore would not be defined as protein feeds.

Broiler litter could be classified as a protein feed on the basis of its digestible protein content (23%). The digestible protein appears to represent 85% of the crude protein, which is in agreement with the results of Smith and Calvert (1976). These values are in contrast to those reported by Van Soest and Robertson (1976) who estimated that the true digestibility of refed animal fecal nitrogen will not exceed 50%. The reason(s) for this discrepancy is unclear. However, based on its ADF and TDN levels, broiler litter could also be classified along with other manures as being more comparable to forages than to protein or energy feeds.

Energy feeds are the second most expensive feedstuff, and if animal manures could be utilized as a substitute for typical energy feeds, a large economic incentive also would be present. However, animal manures should not be classified as energy feeds due to their low energy content. Furthermore, when the ADF and metabolizable energy and metabolizable energy and TDN of typical feedstuffs and animal manures are compared (Figures 6 and 7), animal manures are comparable to forages and not energy feeds.

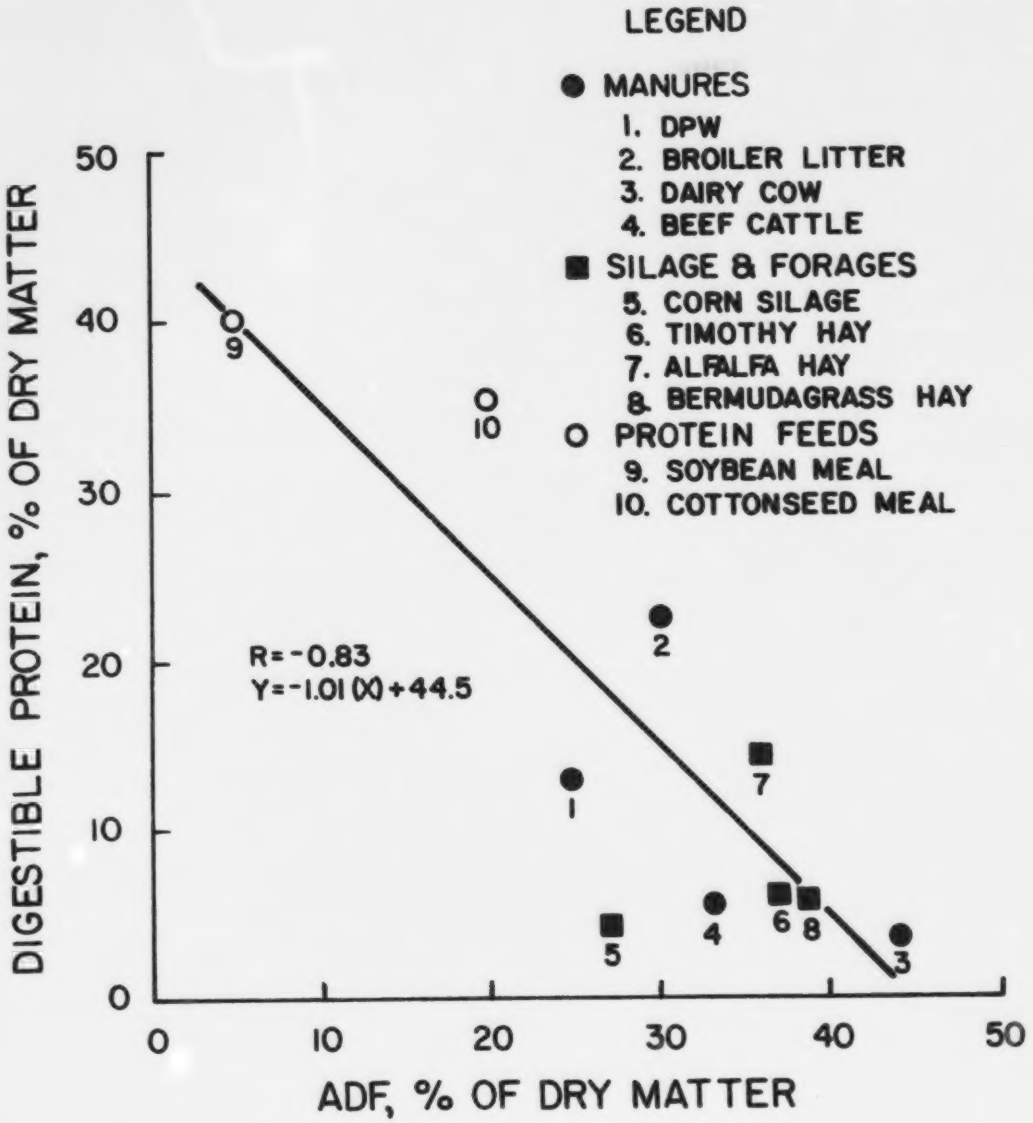

Figure 2. Relationship Between ADF and Digestible Protein Content for Conventional Feedstuffs and Animal Manures

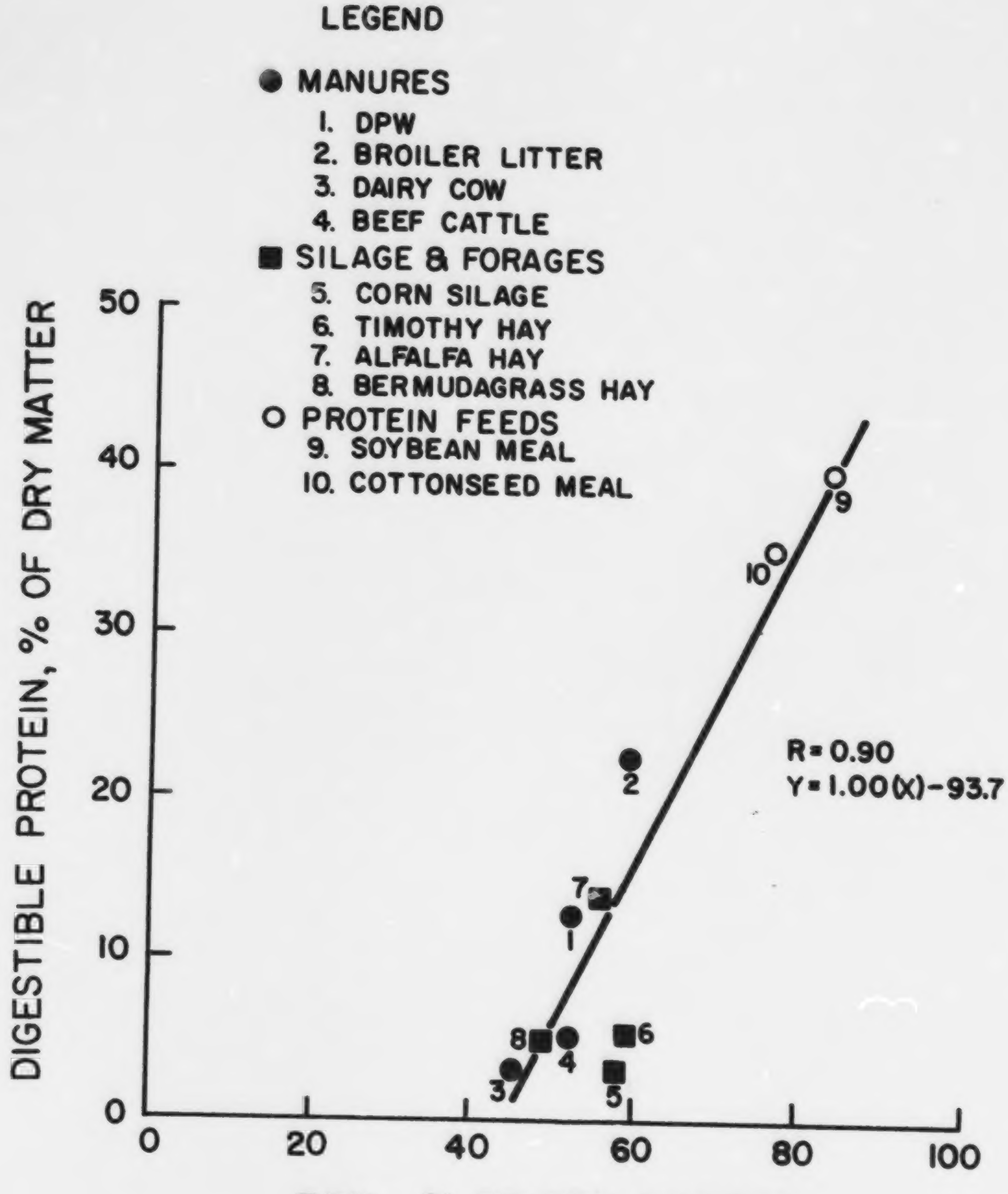

Figure 3. Relationship Between TDN and Digestible Protein Content for Conventional Feedstuffs and Animal Manures

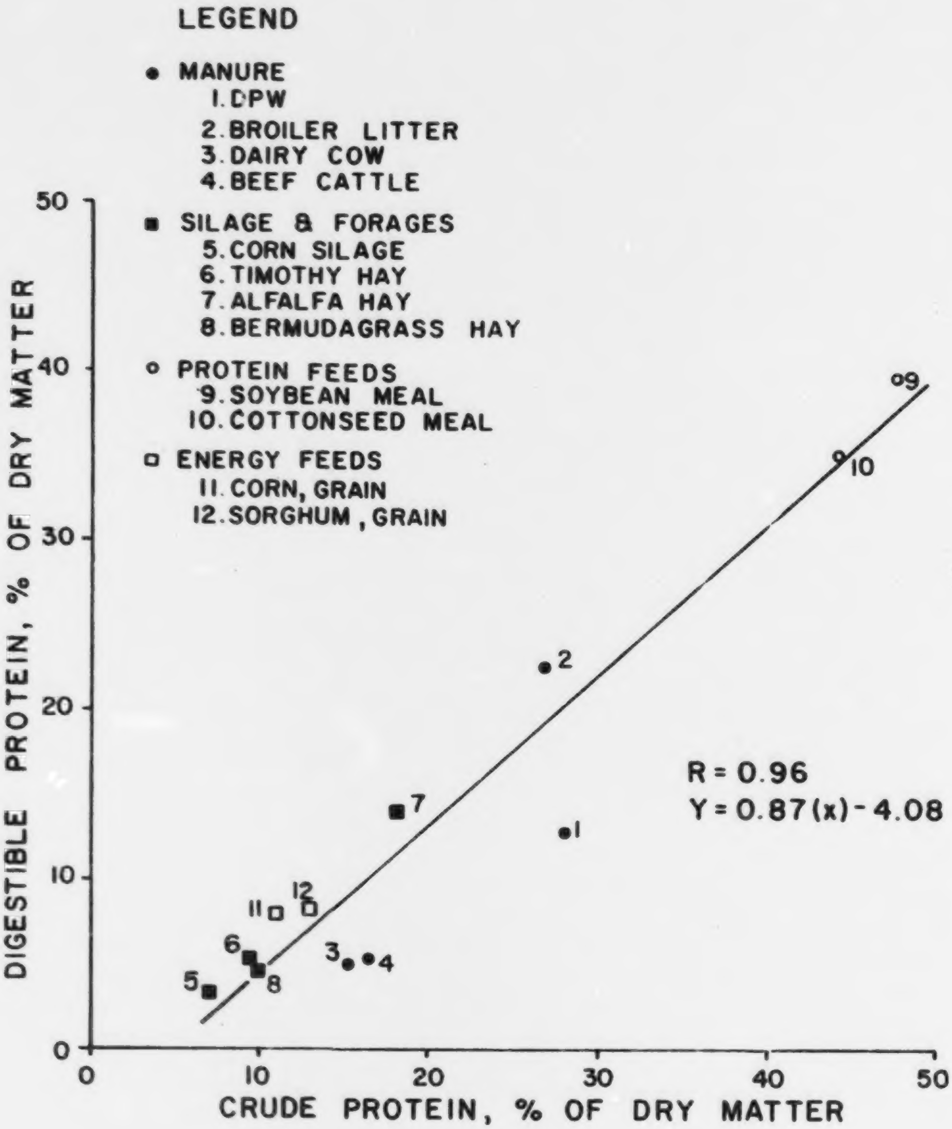

Figure 4. Relationship Between Crude Protein and Digestible Protein Content For Conventional Feedstuffs and Animal Manures

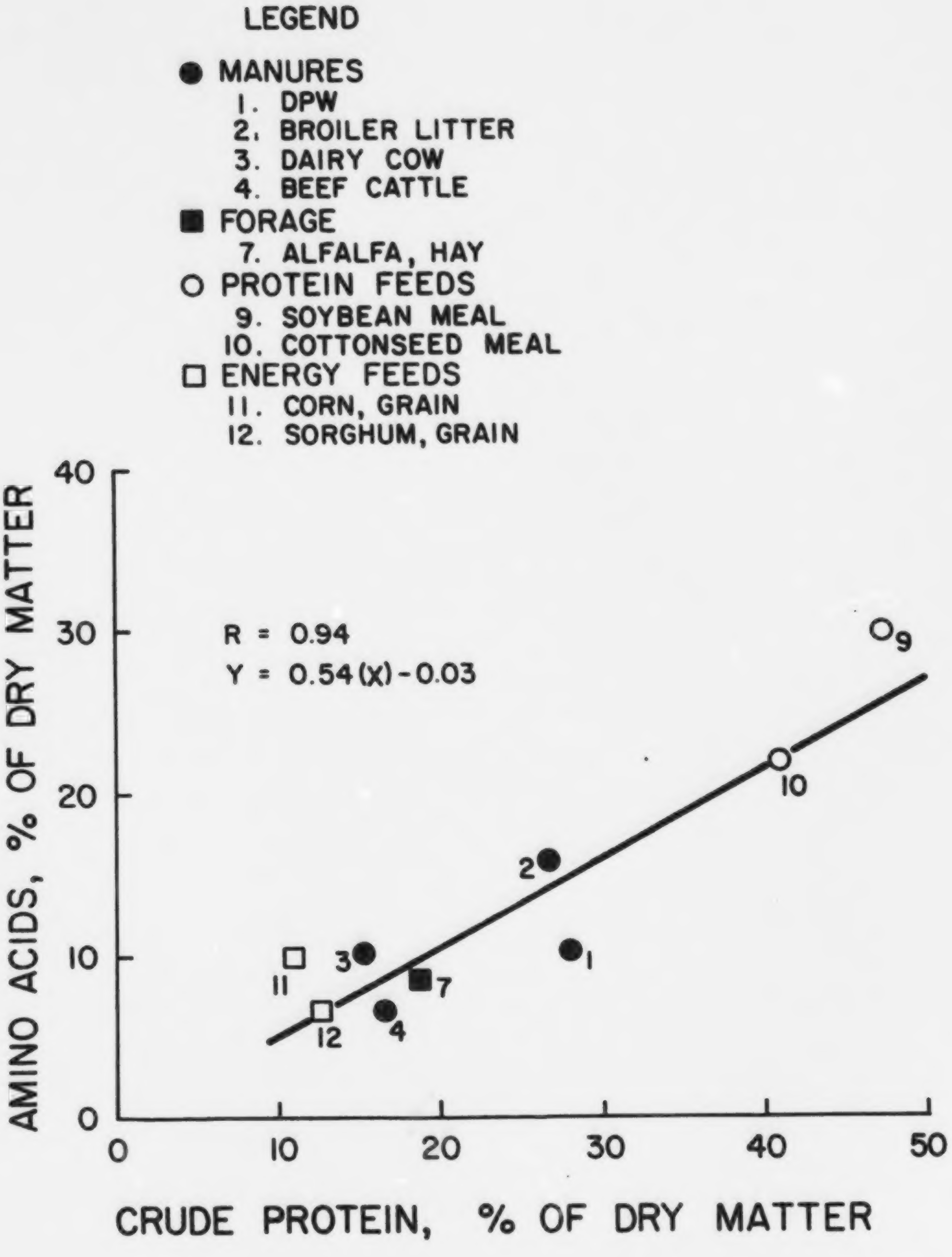

Figure 5. Relationship Between Crude Protein and Amino Acid Content for Conventional Feedstuffs and Animal Manures

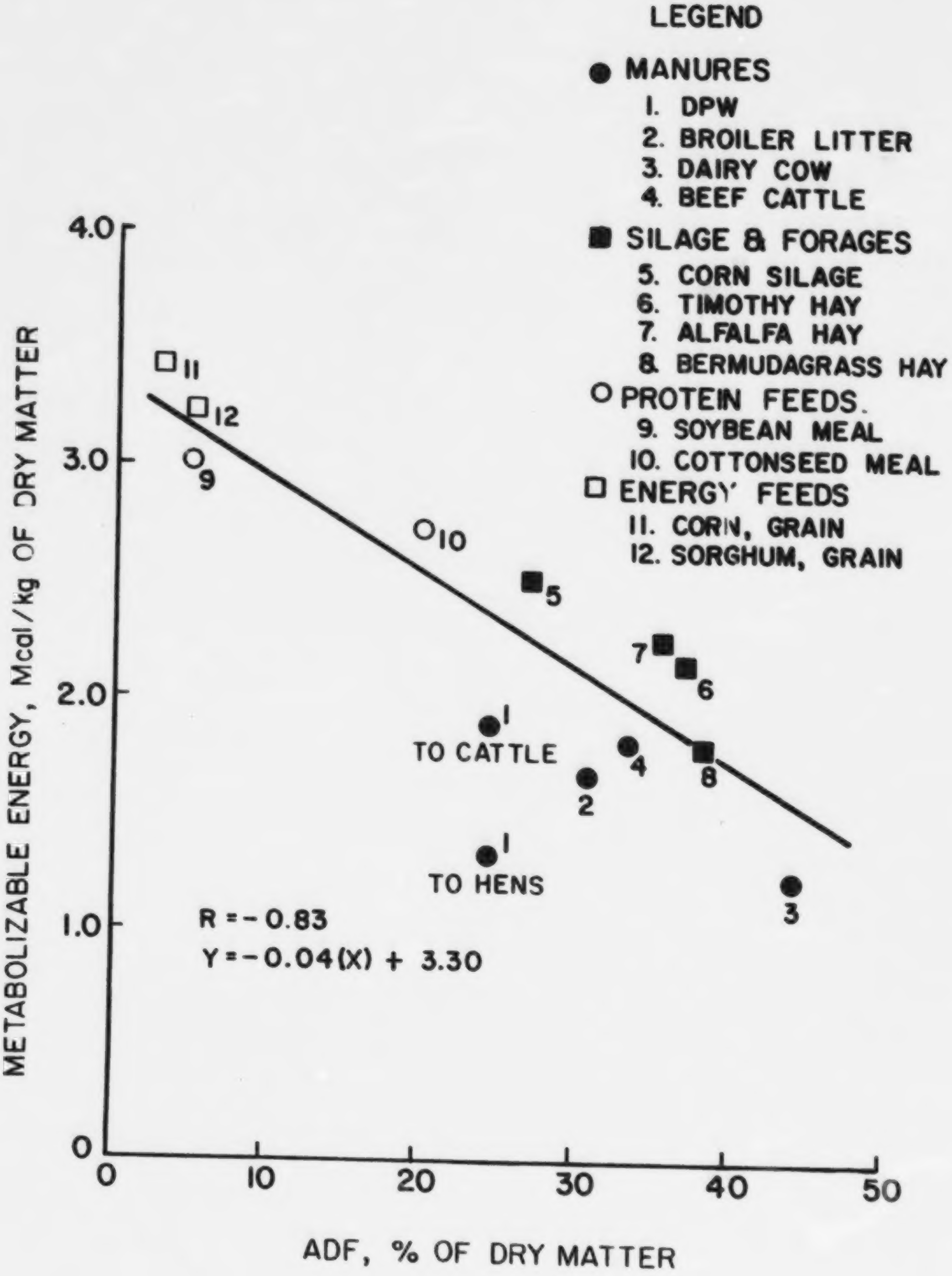

Figure 6. Relationship Between ADF and Metabolizable Energy Content for Conventional Feedstuffs and Animal Manures

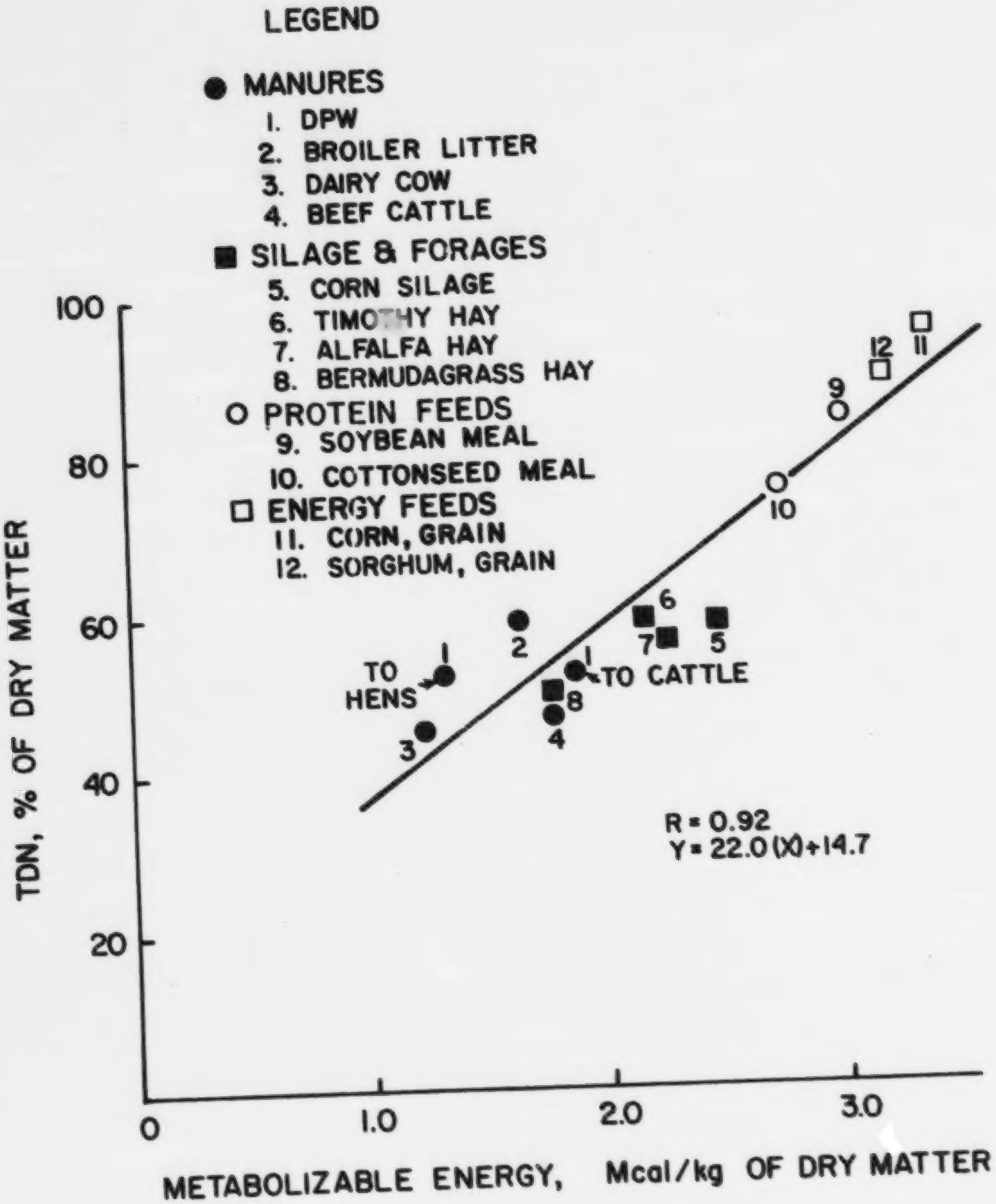

Figure 7. Relationship Between Metabolizable Energy and TDN Content for Conventional Feedstuffs and Animal Manures

The remaining feedstuff category, forages, seems to be the correct classification for animal manures. Broiler litter, cattle and dairy manure all contain more than 18% fiber and therefore may be classified as forages. DPW contains only 13% fiber, and therefore does not fulfill the classical definition of a forage. An alternate method of classification would be to utilize ADF, NDF, and TDN. When these parameters for animal manures and typical feedstuffs are compared, animal manures again are shown to be more comparable to forages than to protein or energy feeds (Figures 8 and 9). Both forages and animal manures are high in ADF and low in TDN, while protein and energy feeds are low in ADF and high in TDN.

In summary, the classification of animal manures as feedstuffs, based upon classical nutritional definitions and their reported nutrient content, indicates that they should be considered to be more comparable to silages or forages (corn silage and alfalfa, timothy and bermudagrass hays) than to protein or energy feeds when fed to ruminants. Animal manures should not be classified as protein feeds (Figure 10). The crude and digestible protein content of DPW, broiler litter, and dairy cow and beef cattle manures are lower than typical protein feeds (soybean and cottonseed meal). The protein levels of beef cattle and dairy cow manures are comparable to protein levels in typical energy feeds (corn and sorghum grain) and silage and forages (corn silage, and alfalfa, timothy and bermudagrass hay). The protein levels of DPW and broiler litter are higher than energy feeds and silage and forages; however, DPW is lower in digestible protein than broiler litter.

Classifying animal manures as energy feeds also is inappropriate (Figure 11). All animal manures are lower in metabolizable energy than energy and protein feeds, and silages and forages. Metabolizable energy levels of broiler litter and cattle manures for poultry have not been reported. The metabolizable energy levels of silage and forages were omitted from the comparison because they are not utilized in typical poultry rations.

Classifying animal manures as comparable to silage and forages seems to be appropriate (Figure 12). All animal manures are higher in fiber than protein and energy feeds.

It is not proper to classify DPW fed to nonruminants on the basis of ADF, NDF, or digestible protein, because these parameters are not pertinent to monogastric nutrition. On the basis of the relationship between the crude protein and amino acid content (Figure 5), DPW should not be classified as a protein feed. The low metabolizable energy content of DPW to nonruminants, in contrast to typical energy feeds (Figure 11), also indicates that DPW is not an energy feed. The classification of DPW as a feed for nonruminants is best summarized by Nesheim (1972) who suggested that it should be considered as a source of minerals and perhaps some amino acids.

ESTIMATION OF ECONOMIC VALUE

The nutrient evaluations in the previous sections have established a basis for estimating the economic value of DPW, broiler litter, and cattle

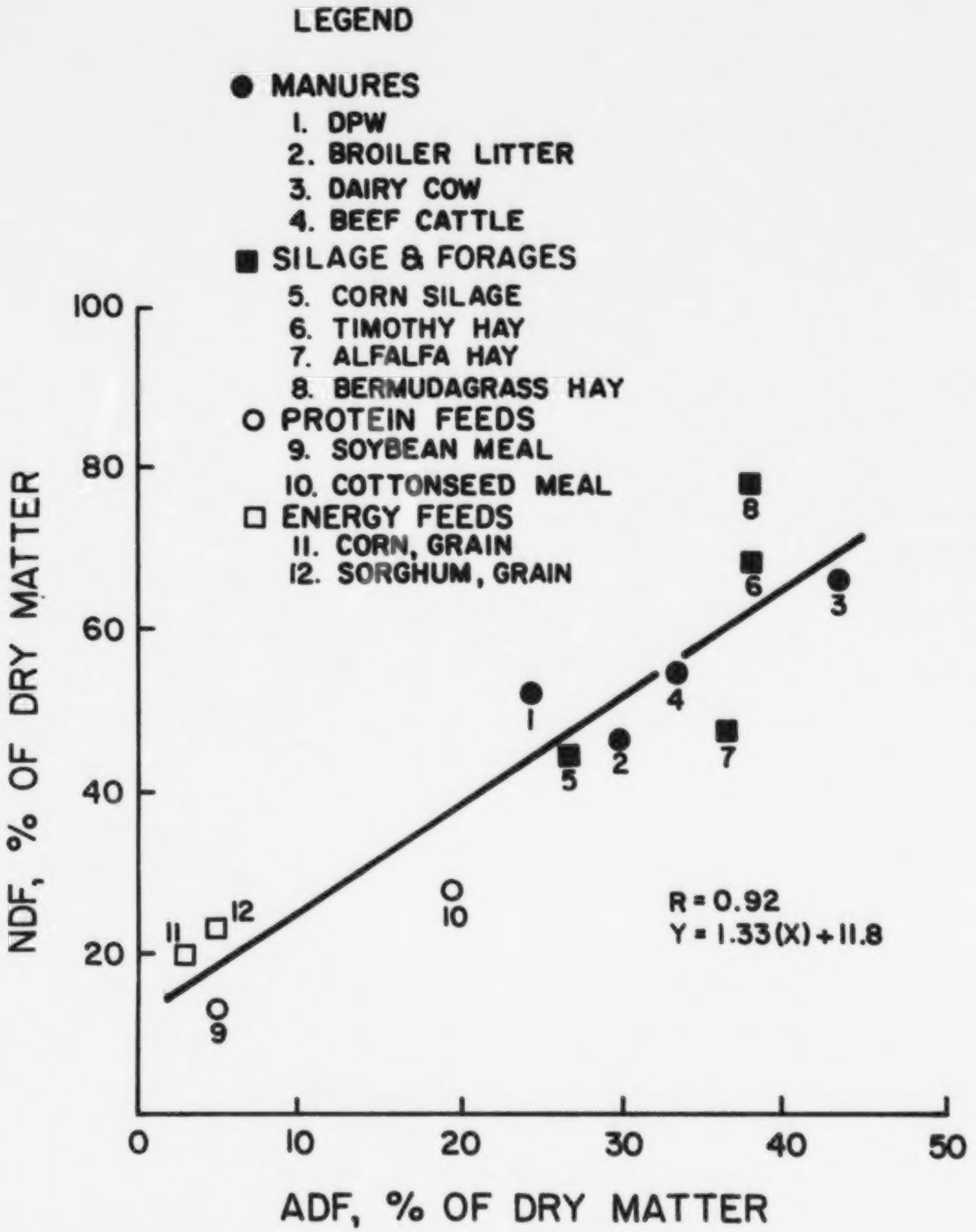

Figure 8. Relationship Between ADF and NDF Content for Conventional Feedstuffs and Animal Manures

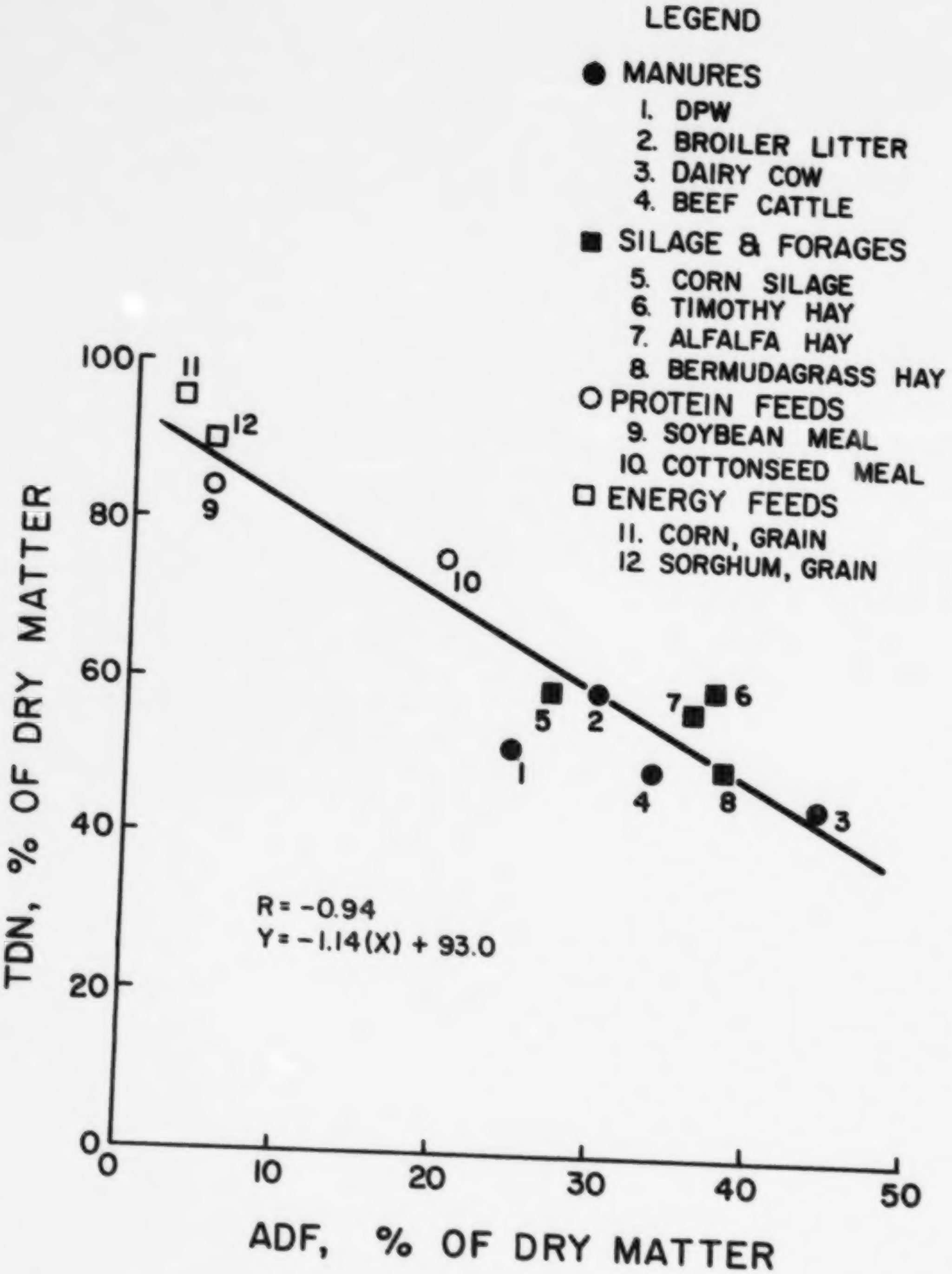

Figure 9. Relationship Between ADF and TDN Content for Conventional Feedstuffs and Animal Manures

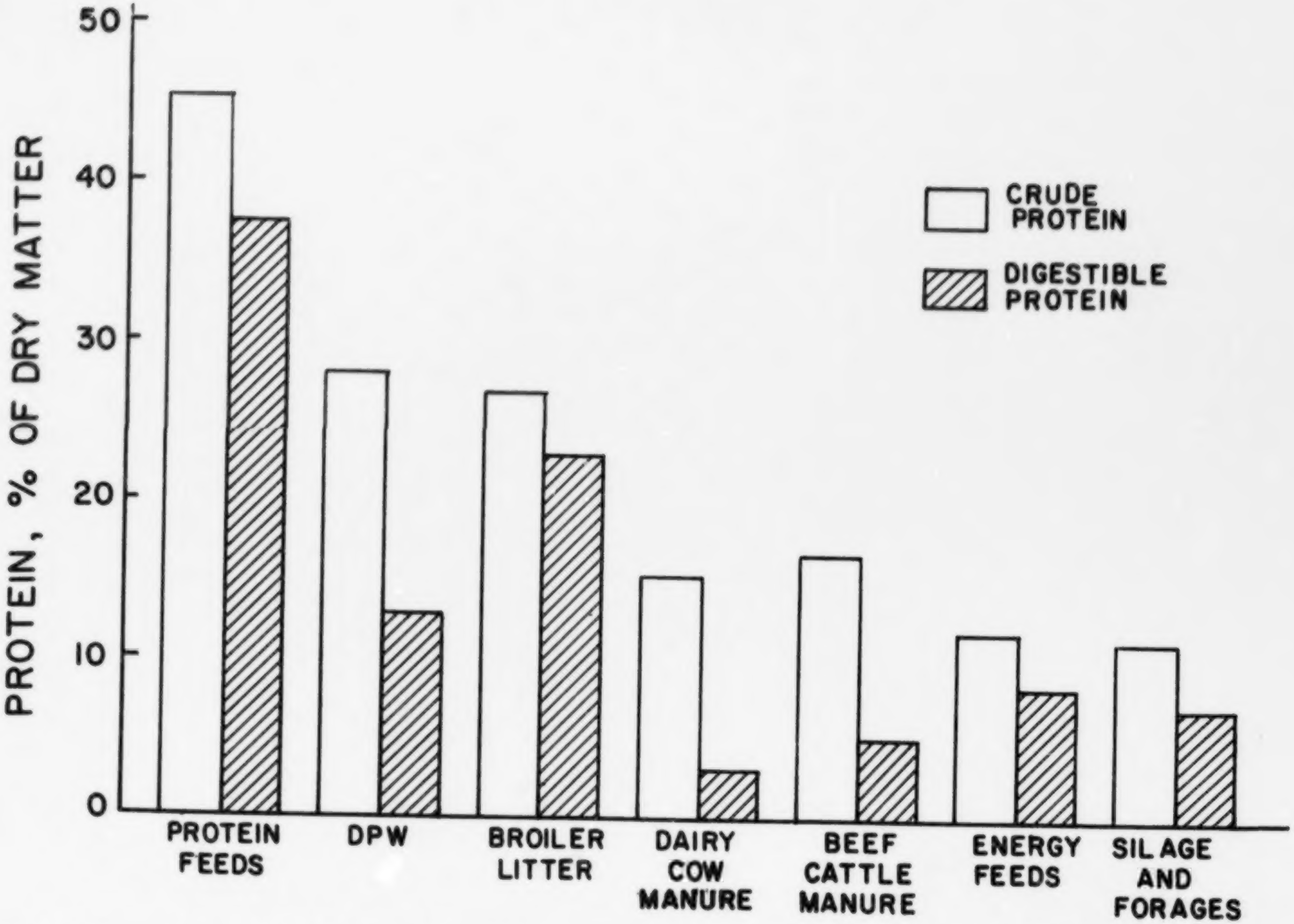

Figure 10. Comparison of Crude and Digestible Protein Contents for Conventional Feedstuffs and Animal Manures

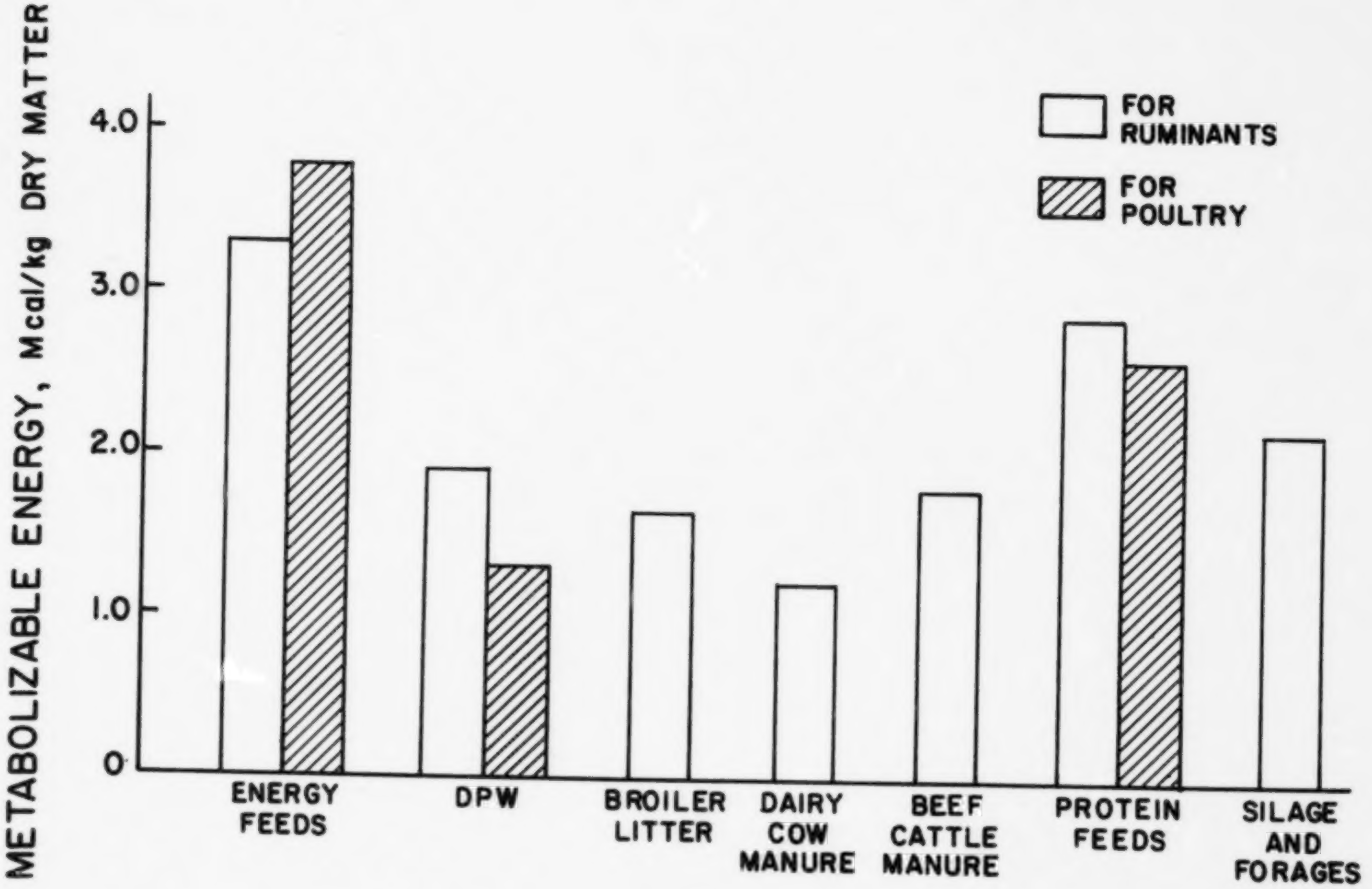

Figure 11. Comparison of Metabolizable Energy Content for Conventional Feedstuffs and Animal Manures

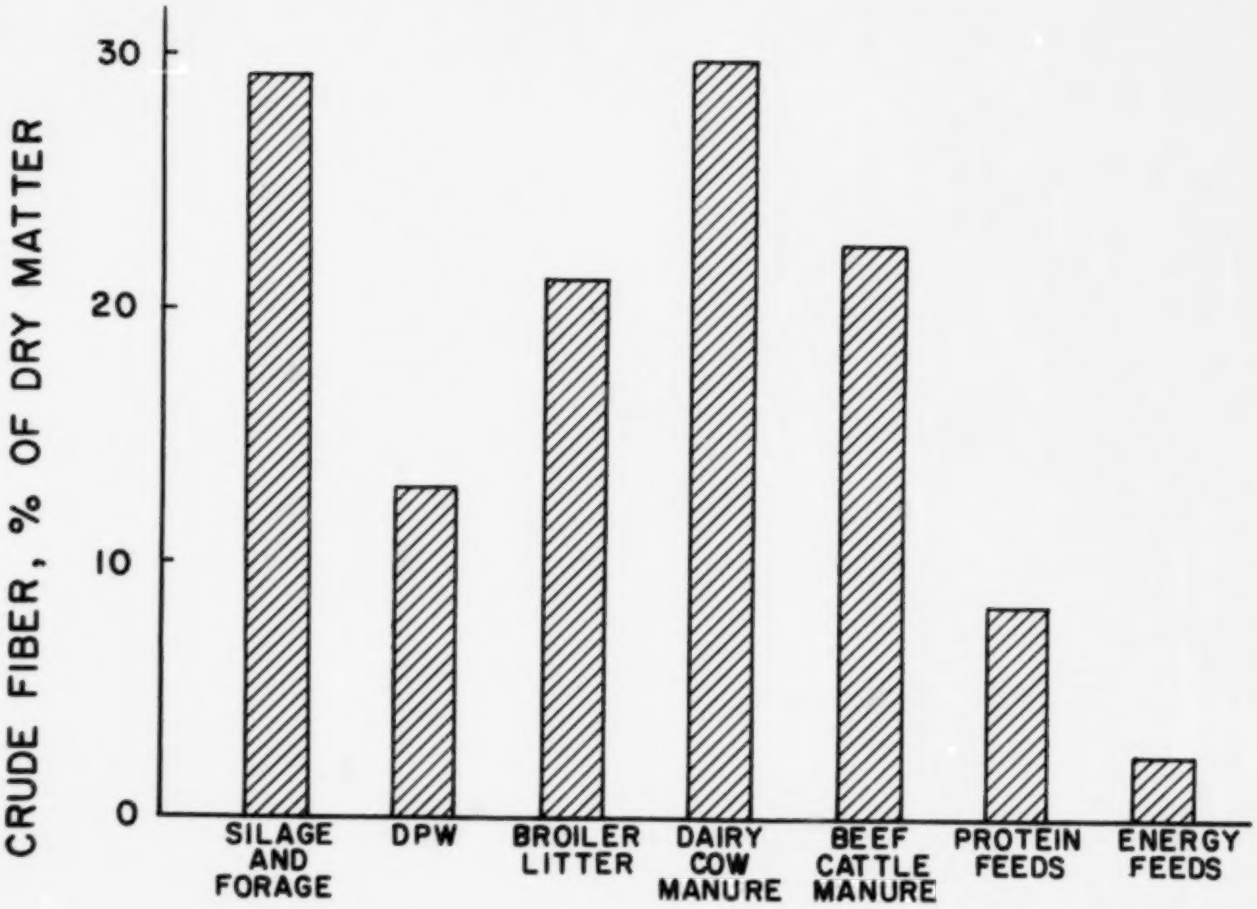

Figure 12. Comparison of Crude Fiber Contents for Conventional Feedstuffs and Animal Manures

manures as feedstuffs. In that animal manures are not commercially bought and sold, no market exists to establish monetary values for these manures as feedstuffs. It is, however, possible to estimate the economic value of these materials based on market prices of analogous conventional feedstuffs. In the previous section, it has been established that DPW, broiler litter, and dairy cow and beef cattle manures are more comparable to corn silage and forages (alfalfa, timothy and bermudagrass hay) than to protein or energy feeds on the basis of their nutrient characteristics when used as feedstuffs for ruminants.

The economic value of the poultry and cattle manures was determined by assuming that they were substituted for silage and forage in animal rations and by calculating the economic value as the value of the substituted silage or forage. For example, when broiler litter is substituted on a 1:1 basis for 20% of the corn silage component of a ruminant ration and animal performance is not adversely affected, the economic value of the broiler litter should be equivalent to the economic value of the corn silage replaced.

The economic values of DPW, broiler litter, and dairy cow and beef cattle manures used as feedstuffs for ruminants were estimated as follows:

1. The market cost of 26% dry matter corn silage was $15 per tonne (1979). Its dry matter cost is calculated by dividing $15 by 26%, which equals $58 per tonne.

2. The market cost of 90% dry matter hay was $72 per tonne (1979). Its dry matter cost is calculated by dividing $72 by 90%, which equals $80 per tonne.

3. On a nutrient basis, 1 unit of manure dry matter is equivalent to 1 unit of corn silage or hay dry matter; therefore the values of these manures on a dry basis when used as replacements for corn silage and hay are $58 per tonne and $80 per tonne, respectively.

4. The "as collected" value of animal manures was calculated by multiplying the dry matter economic value of the manures by the dry matter content of the manure as excreted.

5. The following dry matter values were used to calculate the "as collected" value: DPW = 85%, poultry manure as excreted = 25%, broiler litter = 80%, dairy cow manure = 15.5%, and beef cattle manure = 21%.

6. As an example, the calculation of the "as collected" value of broiler litter is:

    A. 1 tonne of broiler litter dry matter is equivalent to 1 tonne of corn silage dry matter = $58.

        1. The dry matter of broiler litter = 80%
        2. The "as collected" value of broiler litter is calculated by multiplying $58 by 80%, which equals $46 per tonne.

B. 1 tonne of broiler litter dry matter is equivalent to 1 tonne of hay dry matter = $80.

1. The dry matter of broiler litter = 80%
2. The "as collected" value of broiler litter is calculated by multiplying $80 by 80%, which equals $64 per tonne.

The estimated value of animal manures when fed to ruminants (dry matter basis) is $58 per tonne when equated to corn silage and $80 per tonne when equated to hay (Table 17). The "as collected" values of the manures reflect the differences in dry matter content of the manures as excreted and range from a low of $9 per tonne for dairy cow manure to a high of $64 per tonne for broiler litter.

The nutritive value of DPW, utilized as a feedstuff for laying hens, was not clearly determined in the previous section. Its value has been attributed to its mineral and amino acid content (Nesheim, 1972). Therefore, the estimated economic value of DPW was compared to a feedstuff containing phosphorus and amino acids (meat and bone meal). This estimated value does not result from a 1:1 substitution because of the quantitative nutrient differences between DPW and meat and bone meal. The following assumptions and calculations were utilized to estimate the economic value of DPW as a feedstuff for laying hens:

1. The market cost of 93% dry matter meat and bone meal is $250 per tonne. Its dry matter cost is calculated by dividing $250 by 93%, which equals $269 per tonne.

2. The ratio of the phosphorus content of meat and bone meal to that of DPW is 2.3:1.

3. The dry matter value of meat and bone meal ($269) was divided by 2.3 to yield a value for DPW of $117 per tonne of dry matter.

4. Because DPW contains 85% dry matter, the as collected value is calculated by multiplying the $117 per tonne of dry matter by 85% to yield a value of $99 per tonne.

5. Poultry manure as excreted contains 25% dry matter; therefore the excreted value is calculated by multiplying $117 per tonne of dry matter by 25% to yield a value of $29 per tonne.

These estimates of the economic value of DPW are probably an overestimate, because the amino acid to phosphorus ratio is higher for the meat and bone meal than DPW. It does, however, provide a reference point.

In summary, these estimated economic values of animal manure suggest that they have value as animal feeds. These values are, however, significantly lower than some of the more costly feedstuffs, such as soybean meal which has a market value of $216 per tonne (Feedstuffs, 1979). The value of these manures as feedstuffs is generally higher than their value as sources of plant nutrients (Table 18). It should be recognized that the

TABLE 17. ESTIMATION OF THE ECONOMIC VALUE OF ANIMAL MANURES

Animal Manure	Species Fed	Conventional Feedstuff Comparable To	Cost of Conventional Feedstuffs per Tonne		Estimated Value of Manure per Tonne	
			Market Cost	Dry Matter Cost	Dry Matter Basis	As Collected Basis
DPW	Laying Hen	Meat and Bone Meal	$250	$269	$117	$99*(29†)
	Ruminant	Corn Silage	15	58	58	49*(14†)
		Hay	72	80	80	68*(20†)
Broiler Litter	**Ruminant**	**Corn Silage**	15	58	58	46‡
		Hay	72	80	80	64‡
Dairy Cow	Ruminant	Corn Silage	15	58	58	9§
		Hay	72	80	80	12§
Beef Cattle	Ruminant	Corn Silage	15	58	58	12**
		Hay	72	80	80	17**

*Value based on 85% dry matter

†Value based on 25% dry matter

‡Value based on 80% dry matter

§Value based on 15.5% dry matter

**Value based on 21% dry matter

TABLE 18. A COMPARISON OF THE FERTILIZER VALUE AND ESTIMATED ECONOMIC VALUE OF ANIMAL MANURES*

Animal Manure	Fertilizer Value, Dollars per Tonne†	Estimated --------Economic Value, Dollars per Tonne---------- Used as a Substitute For: Meat & Bone Meal	Corn Silage	Forages
Caged Laying Hens, 25% Dry Matter	12	29	14	20
Broiler Litter, 80% Dry Matter	32	--	46	64
Dairy Cow, 15.5% Dry Matter	3	--	9	12
Beef Cattle, 21% Dry Matter	5	--	12	17

* Feedstuff value from Table 17

† See appendix D

economic values for manures as feedstuffs presented in this section are only estimates. The true value of these materials as feedstuffs can only be determined via animal response as identified in animal feeding trials.

SECTION 6

NUTRIENT CHARACTERISTICS OF PROCESSED ANIMAL MANURES

INTRODUCTION

This section evaluates the reported information on the nutrient characteristics of aerobically and anaerobically digested manures, cattle manure screenings, and Cereco products. The characteristics are compared to conventional feedstuffs on a nutrient and economic basis in order to identify the relative value of these other processed animal manures as potential feedstuffs.

AEROBICALLY DIGESTED MANURES

Aerobic digestion is a biological treatment process that uses microorganisms to metabolize organic matter and synthesize microbial solids. Oxidation ditches are an example of aerobic biological treatment systems that have been used for the digestion of manures. Several studies have demonstrated the value of including biologically processed oxidation ditch mixed liquor (ODML) as a feedstuff.

The nutrient characteristics of aerobically digested animal wastes are shown in Table 19. On the basis of the limited available data, swine ODML is higher in crude protein than swine ODML settled solids. The amino acid composition of swine and laying hen ODML is shown in Table 20.

ANAEROBICALLY DIGESTED MANURES

Anaerobic digestion has been used successfully to produce biogas (methane) from animal wastes. However, the economic value of the methane does not appear to offset the required capital investments (Jewell et al., 1976; 1978; Hashimoto et al., 1978; 1979). It has been suggested that the contents of an anaerobic digestor may have a nutritive and economic value as a feedstuff that would defray some of the capital investment (Jewell et al., 1976). The nutritive value of anaerobic digestor effluent has been attributed to an enriched protein content that results from fermentation (Prior and Hashimoto, 1980). The economic value of the digestor contents is based upon its utilization as a substitute for soybean meal (Hashimoto et al., 1978). The dried cake, obtained by centrifuging the effluent and drying the resultant product, also has been suggested to have value as a substitute for alfalfa hay (Hashimoto et al., 1978), and a wet cake, obtained

TABLE 19. NUTRIENT CHARACTERISTICS OF AEROBICALLY DIGESTED ANIMAL WASTES

Composition of Dry Matter, %	Laying Hen ODML*	Swine ODML†	Swine ODML Settled Solids‡	Beef Settled Solids§
Dry matter	1.4	3	–	20
Crude Protein	29.5	49.0	27.7	15.2
Ash	40.5	41.7	-	-
Calcium	-	3.33	1.6	-
Phosphorus	2.69	3.83	1.5	-
Potassium	-	4.14	-	-
Magnesium	-	1.49	-	-
Sodium	-	2.75	-	-
Iron	-	0.55	-	-
Copper	-	0.007	-	-
Zinc	-	0.115	-	-
TDN	-	-	-	48.5
ADF	-	-	-	21.6
NDF	-	-	-	56.1
Lignin	-	-	-	6.3

* Martin _et_ _al_. (1976); Martin (1980)

† Harmon _et_ _al_. (1973, 1975)

‡ Harmon _et_ _al_. (1972)

§ Hegg _et_ _al_. (1974, 1975)

TABLE 20. AMINO ACID COMPOSITION OF AEROBICALLY DIGESTED ANIMAL WASTES

Amino Acid	Swine ODML*	Laying Hen ODML †
	-------- Percent of Dry Matter	------------
Arginine ‡	1.28	1.70
Cystine	-	0.17
Glycine	2.29	1.57
Histidine ‡	0.47	0.74
Leucine ‡	2.79	1.86
Isoleucine ‡	1.49	1.20
Lysine ‡	1.42	1.80
Methionine ‡	0.77	0.51
Phenylalanine ‡	1.48	1.17
Tyrosine	1.17	0.80
Valine ‡	2.06	1.68
Alanine	2.83	1.83
Proline	1.29	1.00
Glutamic Acid	5.06	3.34
Serine	2.55	0.86
Threonine ‡	1.96	1.26
Aspartic Acid	3.73	2.46
Tryptophan ‡	0.28	-
Total Amino Acids	32.92	23.95
Essential Amino Acids	14.0	11.92
% of total	42.5	49.8

*Harmon et al. (1973, 1975)
†J. Martin, Jr., Unpublished data (1980)
‡Essential Amino Acids

by centrifuging the effluent, has been suggested to have value as a substitute for cottonseed meal (Burford and Varani, 1978; Prior and Hashimoto, 1980).

Nutrient characteristics of the dried cake and wet cake are shown in Table 21. The crude protein content of the wet cake is higher than the dried cake content indicating that the wet cake may be a better source of protein than the dried cake. The amino acid composition of the dried cake is shown in Table 22. The total and essential amino acid content of the anaerobically digested steer manure is higher than that of as collected beef cattle manure (Table 15).

The nutrient characteristics of mesophilic and thermophilic anaerobic digestor influent and effluent utilizing dairy manure as a substrate are shown in Table 23. The effluent of both digestors is lower in digestible carbohydrates, cellulose and hemicellulose, and higher in indigestible components, lignin and ash, than the influent. This indicates that the

TABLE 21. NUTRIENT CHARACTERISTICS OF ANAEROBICALLY DIGESTED STEER MANURE (55°C)

Component	Dried Cake (*)(†)	Wet Cake (‡)
Dry Matter (%)	92.0	23.0
Composition of Dry Matter, %		
Crude Protein	18.2	24.5
Digestible Protein	-	18.7
Ash	23.3	37.9
Calcium	0.69	-
Phosphorus	1.63	-
TDN	-	61.0
Metabolizable Energy, Mcal/kg	-	2.20

(*) Hashimoto *et al.* (1978)
(†) Prior and Hashimoto (1980)
(‡) Burford and Varani (1978)

TABLE 22. AMINO ACID COMPOSITION OF DRIED CAKE* (Anaerobically Digested Steer Manure, 55°C)

Amino Acid	Percent of Dry Matter
Arginine †	0.53
Glycine	0.76
Histidine †	0.24
Leucine †	1.10
Isoleucine †	0.62
Lysine †	0.62
Methionine †	0.15
Phenylalanine †	0.53
Tyrosine	0.28
Valine †	0.68
Alanine	0.82
Proline	0.69
Glutamic Acid	2.09
Serine	0.43
Threonine †	0.57
Aspartic Acid	1.23
Total Amino Acids	11.34
Essential Amino Acids	5.04
% of Total	44.4

* Prior and Hashimoto (1980)
† Essential Amino Acids

TABLE 23. NUTRIENT CHARACTERISTICS OF MESOPHILIC AND THERMOPHILIC ANAEROBICALLY DIGESTED DAIRY COW MANURE (Jewell *et al.*, 1978).

Component	Mesophilic*		Thermophilic †	
	Influent	Effluent	Influent	Effluent
Dry Matter (%)	8.00	5.34	7.00	5.42
	% of Dry Matter		% of Dry Matter	
NDF	50.66	45.33	55.86	52.40
ADF	32.34	32.22	34.73	35.72
Cellulose	24.18	21.03	24.26	22.62
Hemicellulose	18.32	13.11	21.12	16.68
Lignin	8.16	11.19	10.47	13.10
Ash	11.43	16.18	10.49	13.01

* 12 day HRT, 35°C, completely mixed

† 5 day HRT, 60°C, completely mixed

potential feedstuff value of the influent has been reduced by the digestion process, and the effluent, apart from bacterial debris, could be considered largely as nonnutritive residues (Van Soest and Robertson, 1978).

Nutrient characteristics of the thermophilic anaerobic digestion of steer manure are shown in Tables 24 and 25. The crude protein and amino acid contents of the effluent have been reported to be "enhanced" when expressed on a dry matter basis (Prior and Hashimoto, 1980). It should be noted that this "enhancement" results from a concentration effect only. When the grams per liter of influent and effluent are determined, to account for solids destruction that occurred during the thermophilic digestion, the amino acid content of the effluent decreased by 9% and the crude protein content decreased by 2.5% (Tables 24 and 25).

CATTLE MANURE SCREENINGS

Mechanical separation converts manure slurries into solid and liquid fractions. The benefits include: (1) liquid fractions that are easier to handle and apply to the land; (2) use of the solid fraction as a potential source of bedding, fertilizer, and possibly a feedstuff; and (3) primary treatment of the slurry prior to storage reducing possible solids handling problems.

Mechanical separators that have been used with manures include: (1) rotary screens; (2) flat belts; (3) roller presses; and (4) vibrating screens. The performance of these and other separators have been reviewed in detail (Johnson *et al.*, 1974; Pain *et al.*, 1978; Wallick *et al.*, 1978). The process involves diluting the manure with water, pumping the slurry onto a separator and obtaining a solid and a liquid fraction.

The characteristics of dairy cow and beef cattle manure screenings are shown in Tables 26 and 27. Considerable variation exists between dairy and beef cattle manure screenings. This variation can be the result of different rations and any uncontrolled mibrobial degradation that might have taken place before the screening process.

CERECO PROCESS PRODUCTS

The Cereco Process developed by Ceres Ecology of New York City is a patented process for producing three products from animal waste (Seckler and Harper, 1978). The process involves mixing ground animal wastes with water and processing the slurry through a series of mixing and liquid-solid separation tanks. The resultant products are: (1) Cereco silage (CI), (2) Cereco protein (CII), and (3) Cereco soil conditioner (CIII).

The nutrient characteristics of CI are shown in Table 28. CI consists of undigested grain and fiber particles from the animal waste and has been suggested as a substitute for corn silage (Ward *et al.*, 1975).

TABLE 24. NUTRIENT CHARACTERISTICS OF THERMOPHILIC ANAEROBICALLY DIGESTED STEER MANURE, 55°C (Prior and Hashimoto, 1980)*

Component	% Influent	% Effluent	-------- grams per liter -------- Influent	Effluent
Dry Matter	7.22	3.98	72.2	39.8 (-44.9)[§]
	------ % of Dry Matter -----			
NDF	41.5	40.1	29.96	15.96 (-46.8)
ADF	15.3	20.0	11.05	7.96 (-28.0)
Cellulose	10.5	10.6	7.58	4.22 (-44.4)
Hemicellulose	26.2	20.1	18.92	8.00 (-57.7)
Lignin	3.1	6.4	2.24	2.55 (+13.8)
Gross Energy	4661[†]	4655[†]	336.5[‡]	185.3[‡] (-45.0)
Amino Acids	14.28	23.53	10.32	9.36 (-9.3)
Crude Protein	34.8	61.6	25.13	24.52 (-2.5)
Ash	9.8	17.1	7.08	6.81 (-3.8)

[*] HRT average of 5 and 12 days, 55°C

[†] kilocalories per gram dry matter

[‡] Megacalories per liter

[§] Percent change

TABLE 25. AMINO ACID COMPOSITION OF DIGESTER INFLUENT AND EFFLUENT (Steer Manure, 55°C)*

Amino Acid	Influent % of D.M.	Influent g/l	Effluent % of D.M.	Effluent g/l
Arginine †	.44	0.32	.96	0.38
Glycine	1.52	1.10	1.38	0.55
Histidine †	.27	0.19	.44	0.18
Leucine †	1.11	0.80	2.12	0.84
Isoleucine †	.63	0.45	1.37	0.55
Lysine †	.77	0.56	1.48	0.59
Methionine †	.26	0.19	.49	0.19
Phenylalanine †	.62	0.45	1.26	0.50
Tyrosine	.33	0.24	.79	0.31
Valine †	.76	0.55	1.53	0.61
Alanine	2.07	1.49	1.63	0.65
Proline	.67	0.48	1.14	0.45
Glutamic Acid	2.46	1.78	4.54	1.81
Serine	.48	0.35	.83	0.33
Threonine †	.62	0.45	1.09	0.43
Aspartic Acid	1.27	0.92	2.48	0.99
	14.28	10.32	23.53	9.36
Essential Amino Acids	5.48	3.96	10.74	4.27
% of Total	38.4	38.4	45.6	45.6

* Prior and Hashimoto (1980)

† Essential amino acids

TABLE 26. NUTRIENT CHARACTERISTICS OF DAIRY COW MANURE SCREENINGS

Composition of Dry Matter, %	Mean	Range	Number of Observations	Source*
Crude Protein	9.9	6.9-12.5	3	1,2,3
Ether Extract	1.6	-	1	3
Crude Fiber	38.8	-	1	3
TDN	55	-	1	3
ADF	46.7	42.1-52.0	3	1,2,3
NDF	74.4	66.1-85.0	3	1,2,3
Lignin	11.1	10.0-12.0	3	1,2,3
Ash	6.8	-	1	3
Calcium	1.45	-	1	3
Phosphorus	0.26	-	1	3
Potassium	0.99	-	1	3
Gross Energy, Kcal/kg	4490	-	1	3

*Numbers refer to the following sources:
1 - Johnson _et_ _al_. (1974)
2 - Johnson _et_ _al_. (1975b)
3 - Van Soest and Robertson (1980)

TABLE 27. NUTRIENT CHARACTERISTICS OF BEEF CATTLE MANURE SCREENINGS

Composition of Dry Matter, %	Mean	Range	Number of Observations	Source*
Crude Protein	13.4	12.8-14.0	2	1,2
Ether Extract	1.0	-	2	1,2
Crude Fiber	35.9	35.0-36.8	2	1,2
NFE	44.0	-	1	1
NDF	82.0	-	1	1
Ash	5.8	5.7-6.0	2	1,2
Calcium	0.94	-	1	2
Phosphorus	0.24	-	1	2
Gross Energy, Kcal/kg	4600	-	1	1
Dry Matter, %	31.0	27.0-35.1	2	1,2

*Numbers refer to the following sources:
1 - Richter and Shirley (1977)
2 - Schake _et_ _al_. (1977)

TABLE 28. NUTRIENT CHARACTERISTICS OF CERES PRODUCT CI - CERECO SILAGE

Composition of Dry Matter, %	Mean	Range	Number of Observations	Source*
Crude Protein	9.4	9.0-10.3	3	2,5,6
Ether Extract	1.3	0.8-1.8	2	5,6
Crude Fiber	27.7	27.5-28.0	2	2,6
NFE	42.0	33.7-50.4	2	5,6
TDN	60.1	60.0-60.2	2	2,6
ADF	45.4	-	1	5
NDF	73.9	-	1	5
Lignin	18.0	-	1	5
Ash	9.8	-	1	5
Calcium	0.50	-	1	2
Phosphorus	0.15	-	1	2
Energy, Kcal/kg				
Digestible Energy	2740	-	1	6
Metabolizable Energy	2220	-	1	6
Net Energy - Maintenance	1780	-	1	6
- Growth	1510	-	1	6
Dry Matter, %	42.2	34.4-50.0	2	2,6

* See appendix A

The nutrient and amino acid composition of the CII is shown in Tables 29 and 30. CII is a dry pelleted protein feed that has been suggested as a substitute for soybean meal and/or corn (Ward *et al.*, 1975). CII has a high ash content and may pose a problem in a continuously recycled system. The amino acid content of CII is higher than that of corn, but lower than that of conventional protein feeds. It has been reported that when CII is mixed with soybean meal, a complementarity of lysine and sulfur containing amino acids occurs (Kienholz, *et al.*, 1975). The CIII product consists of dirt, plant residues and other indigestible materials in manure, contains 1% nitrogen, 0.5% phosphorus and 0.5% potassium, and can be used to provide humus and plant nutrients for household plants, gardens and agricultural crops (Seckler and Ward, 1974).

COMPARISON TO AS COLLECTED OR DRIED MANURES

Although the crude protein content of aerobically digested swine ODML settled solids is higher than as collected swine manure, the total and essential amino acids and mineral contents are lower than that of as collected swine manure (Table 31). The crude protein, total amino acids and minerals of aerobically digested swine ODML are higher than as collected swine manure (Table 31). Because of limited reported information on the nutrient characteristics of aerobically digested swine manure, conclusive comparisons to as collected swine manure cannot be made.

Before any direct comparisons are made between laying hen ODML and DPW, a mass balance should be conducted to account for the differences in dry matter content. However, on the basis of the dry matter composition, ODML is similar to DPW in phosphorus levels and has a higher crude protein level. The ash content is increased due to the volatile solids destruction that occurs during the digestion process (Table 32). Although the amino acid content of ODML increased 135%, it could not be ascertained if enhancement occurred because solids destruction for the ODML was not reported.

The nutrient characteristics of beef cattle ODML settled solids and as collected beef cattle manure arereported in Table 33. The ODML settled solids are lower in crude protein than as collected cattle manure, and therefore their nutritive value may be less. The crude protein and metabolizable energy contents of the wet cake obtained from centrifuging anaerobic digestor effluent indicates that it should have a higher nutritive value than as collected beef cattle manure (Table 33). The slightly increased crude protein and slightly decreased ash content of the dried centrifuge cake indicates that it should have nominally improved nutritive value when compared to as collected cattle manure. The amino acid content of both the influent and effluent from the anaerobic digestor are higher than as collected cattle manure. The nutrient characteristics of beef cattle screenings are similar to as collected cattle waste, except that the ash content of the screenings is much lower (Table 33).

The Cereco Process has utilized manure from beef cattle, dairy cows and swine for the production of CI, CII, and CIII products. Nutrient characteristics reported in the previous section were for manure from feedlot

TABLE 29. NUTRIENT CHARACTERISTICS OF CERES PRODUCT CII - CERECO PROTEIN

Composition of Dry Matter, %	Mean	Range	Number of Observations	Source*
Crude Protein	26.5	21.6-31.6	6	1,3,5,6,7
Ether Extract	5.4	2.8-11.5	5	1,5,6,7
Crude Fiber	3.1	0.6-5.8	5	1,3,6,7
NFE	32.1	23.8-39.6	6	1,3,5,6,7
TDN	68.0	-	1	6
ADF	15.3	13.5-17.1	2	5,8
NDF	17.1	-	1	8
Lignin	5.9	-	1	8
Ash	30.5	26.6-33.6	5	1,5,6,7
Calcium	3.5	-	1	5
Phosphorus	1.3	-	1	5
Metabolizable Energy, Kcal/kg	2300	-	1	6
Dry Matter, %	91.3	87.4-94.1	4	1,6,7

*See appendix A

TABLE 30. AMINO ACID COMPOSITION OF CERES PRODUCT CII - CERECO PROTEIN*

Amino Acid	Percent of Dry Matter
Arginine †	0.88
Cystine	1.09
Glycine	1.24
Histidine †	0.51
Leucine †	0.68
Isoleucine †	0.48
Lysine †	0.60
Methionine †	0.46
Phenylalanine †	0.81
Tyrosine	1.23
Valine †	0.59
Alanine	5.05
Proline	0.85
Glutamic Acid	0.88
Serine	0.44
Threonine †	0.67
Aspartic Acid	0.72
Total Amino Acids	17.18
Essential Amino Acids	5.68
% of Total	33.1

* Kienholz et al. (1975)

†Essential Amino Acids

TABLE 31. A COMPARISON OF THE NUTRIENT CHARACTERISTICS OF AEROBICALLY DIGESTED SWINE MANURE AND AS COLLECTED SWINE MANURE

		-------- Percent of Dry Matter -------				
Manure Type	Dry Matter	Crude Protein	Calcium	Phosphorus	Total Amino Acids	Essential Amino Acids, % of Total
ODML Settled Solids*	100	28	1.60	1.50	6.4	42.8
ODML *	3	49	3.33	3.83	32.9	42.5
As Collected Manure †	25	21	2.92	2.08	16.1	48.9

(*) Tables 19 and 20

† Orr *et al*. (1971)
Robinson *et al*. (1971)
Harmon and Day (1975)
Holland *et al*. (1975)
Overcash *et al*. (1975)
Pearce (1975)
Kornegay *et al*. (1977)

TABLE 32. A COMPARISON OF THE NUTRIENT CHARACTERISTICS OF AEROBICALLY DIGESTED CAGED LAYING HEN MANURE AND DRIED CAGED LAYING HEN MANURE

		---------- Percent of Dry Matter -------				
Manure Type	Dry Matter	Crude Protein	Phosphorus	Ash	Total Amino Acids	Essential Amino Acids, % of Total
ODML*	1.4	40.5	2.69	40.5	23.95	49.4
DPW †	85	28.0	2.29	27.6	10.23	35.5

* Tables 19 and 20
† Tables 4, 5, and 6

TABLE 33. A COMPARISON OF THE NUTRIENT CHARACTERISTICS OF PROCESSED BEEF CATTLE MANURE AND AS COLLECTED BEEF CATTLE MANURE

	----------- Percent of Dry Matter ----------							
Manure Type	Dry Matter	Crude Protein	Calcium	Phosphorus	Ash	Total Amino Acids	Essential Amino Acids, % of Total	---Kcal/kg--- Metabolizable Energy
ODML Settled Solids *	20.0	15.2	-	-	-	-	-	-
Anaerobic: †								
Dried Cake	92	18.2	0.69	1.63	23.3	11.34	44.4	-
Wet Cake	23	24.5	-	-	37.9	-	-	2200
Influent	7	34.8	-	-	9.8	14.28	38.4	-
Effluent	4	61.6	-	-	17.1	23.53	45.6	-
Screenings ‡	31	13.4	0.94	0.24	5.8	-	-	-
Cereco Products: §								
CI	42.2	9.4	0.50	0.15	9.8	-	-	2220
CII	91.3	26.5	3.50	1.30	30.5	17.2	33.1	2300
As Collected # Cattle Waste	21.1	16.5	1.71	0.80	29.2	6.85	42.2	1777

* Table 19

† Tables 21, 22, 24, and 25

‡ Table 27

§ Tables 28, 29, and 30

# Tables 13, 14, and 15

steers; therefore the Cereco products **were compared to as collected beef** cattle manure (Table 33). The CI silage product is lower in crude protein and ash than as collected cattle manure; however, its metabolizable energy content is increased suggesting that the product's nutritive value should be increased. The CII protein product is higher in crude protein, metabolizable energy, amino acids and ash than as collected cattle manure, suggesting that its nutritive value should also be increased.

Dairy cow manure screenings are lower in crude protein, ether extract and ash than as collected dairy manure (Table 34). The lower ash content is important because it should reduce potential palatability problems. The increased ADF and NDF content and decreased crude protein and lignin may be attributed to the type of separation that occurs.

TABLE 34. A COMPARISON OF THE NUTRIENT CHARACTERISTICS OF DAIRY COW MANURE SCREENINGS AND AS COLLECTED DAIRY COW MANURE

	Percent of Dry Matter								
Manure Type	Crude Protein	Ether Extract	NDF	ADF	Lignin	TDN	Ash	Calcium	Phosphorus
Screenings*	9.9	1.6	74.4	46.7	11.1	55	6.8	1.45	0.26
As Collected Dairy Manure†	15.3	3.0	66.0	43.7	14.4	45	13.4	3.88	0.65

* Table 26

† Tables 10 and 11

COMPARISON TO CONVENTIONAL FEEDSTUFFS

In Section 5 it was possible to show the relationship between animal manures, protein, energy, and forage feedstuffs. Unfortunately, due to insufficient information pertaining to the nutrient characteristics of aerobically and anaerobically digested manures, manure screenings, and Cereco products, such detailed comparisons cannot be presented. However, an attempt will be made to indicate relationships between these other processed manures and conventional feedstuffs, based upon the available nutrient characteristics.

Direct comparison of nutrient characteristics of these processed animal manures and conventional feedstuffs is confounded by differences in their physical state, as reflected by their dry matter content (Figure 13). Since swine and caged laying hen ODML and effluent from anaerobic digestors are liquids, direct comparisons to conventional feedstuffs are misleading, especially when expressed as a percent of the dry matter. Therefore, to alleviate differences in dry matter content, the kilograms of a nutrient per tonne of material as produced were calculated by the following equation:

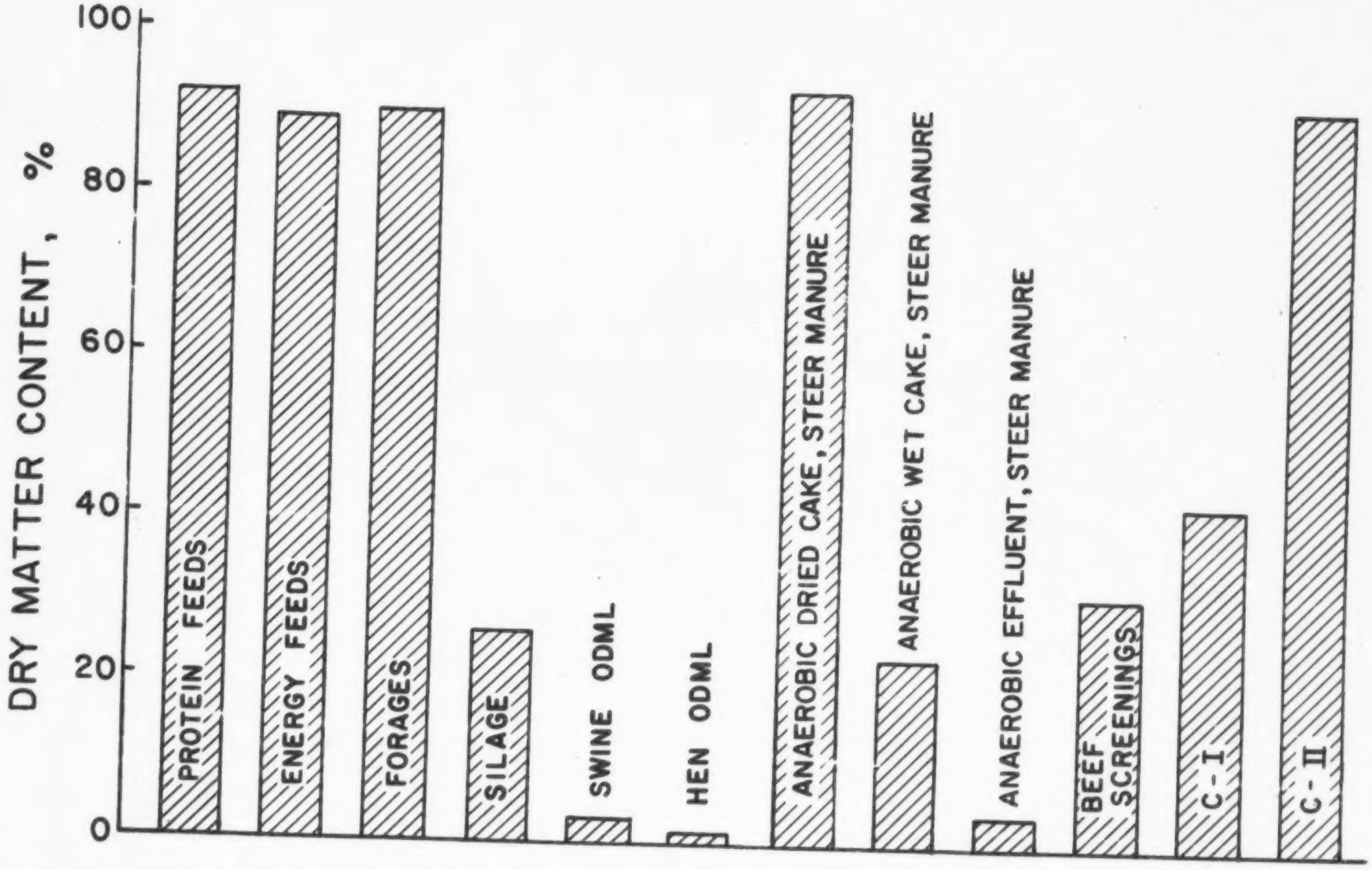

Figure 13. Comparison of Dry Matter Contents for Conventional Feedstuffs and Processed Animal Manures

1000 kg of material as processed x dry matter (%) x nutrients (% of dry matter) = kilograms of nutrient per 1000 kg of material as processed (1)

The amino acid content (% of dry matter) of swine and laying hen ODML and anaerobic digestor effluent are comparable to protein feeds (soybean and cottonseed meal), while the anaerobic digestor dried centrifuged cake and Cereco protein (CII) are lower than protein feeds (Figure 14). When the amino acid content of the other processed animal manures is expressed in kilograms per tonne of material as processed, they are all lower than protein feeds (Figure 14). Although the quantity of amino acids in swine and laying hen ODML is nominal, they are high in essential amino acids, which suggests they may be more analogous to a protein feed than to an energy feed (Table 35).

The crude protein content (% of dry matter) of swine ODML and anaerobic digestor effluent is higher than protein feeds, and all other processed manures are comparable to energy feeds (corn and sorghum grain) or forages (Figure 15). When the crude protein content is expressed in kilograms per tonne of material produced, all other processed animal manures are lower than protein feeds. However, the anaerobic digestor dried centrifuge cake is comparable to forages, and beef cattle manure screenings and Cereco silage (CI) are comparable to corn silage.

The ADF and NDF contents of dairy manure screenings and Cereco silage (Figure 16) are comparable to forages, steer and dairy cow manure and anaerobic digestor effluent appear to be comparable to corn silage, and the Cereco protein is comparable to protein feeds. The metabolizable energy and TDN content of anaerobic digestor wet centrifuge cake, and Cereco silage and protein are comparable to silage and forages (Figure 17).

The classifications of feedstuffs as protein feeds, energy feeds or silages and forages should be based upon their protein, energy and fiber contents (Ensminger and Olentine, 1978). Unfortunately, this information is lacking for most of the other processed animal manures, except the Cereco products. Based upon the protein, metabolizable energy and ADF and NDF content of the Cereco silage, it can be classified as silage and forage feedstuff. Due to the lower metabolizable energy and TDN content of the Cereco protein when compared to protein feeds, it should not be considered a "classical" protein feed.

ESTIMATION OF ECONOMIC VALUE

The previous section failed to delineate conventional feedstuffs that were comparable to these processed animal manures, with the exception of Cereco silage, due to the lack of reported nutrient characteristics. The nutrient characteristics of Cereco silage indicated that it should be classified as a silage or forage; therefore its economic value can be estimated on the basis of market prices of silage and forages. Utilizing the same calculations and assumptions for estimating the economic value of as collected manures (Section 5), Cereco silage estimated economic value is:

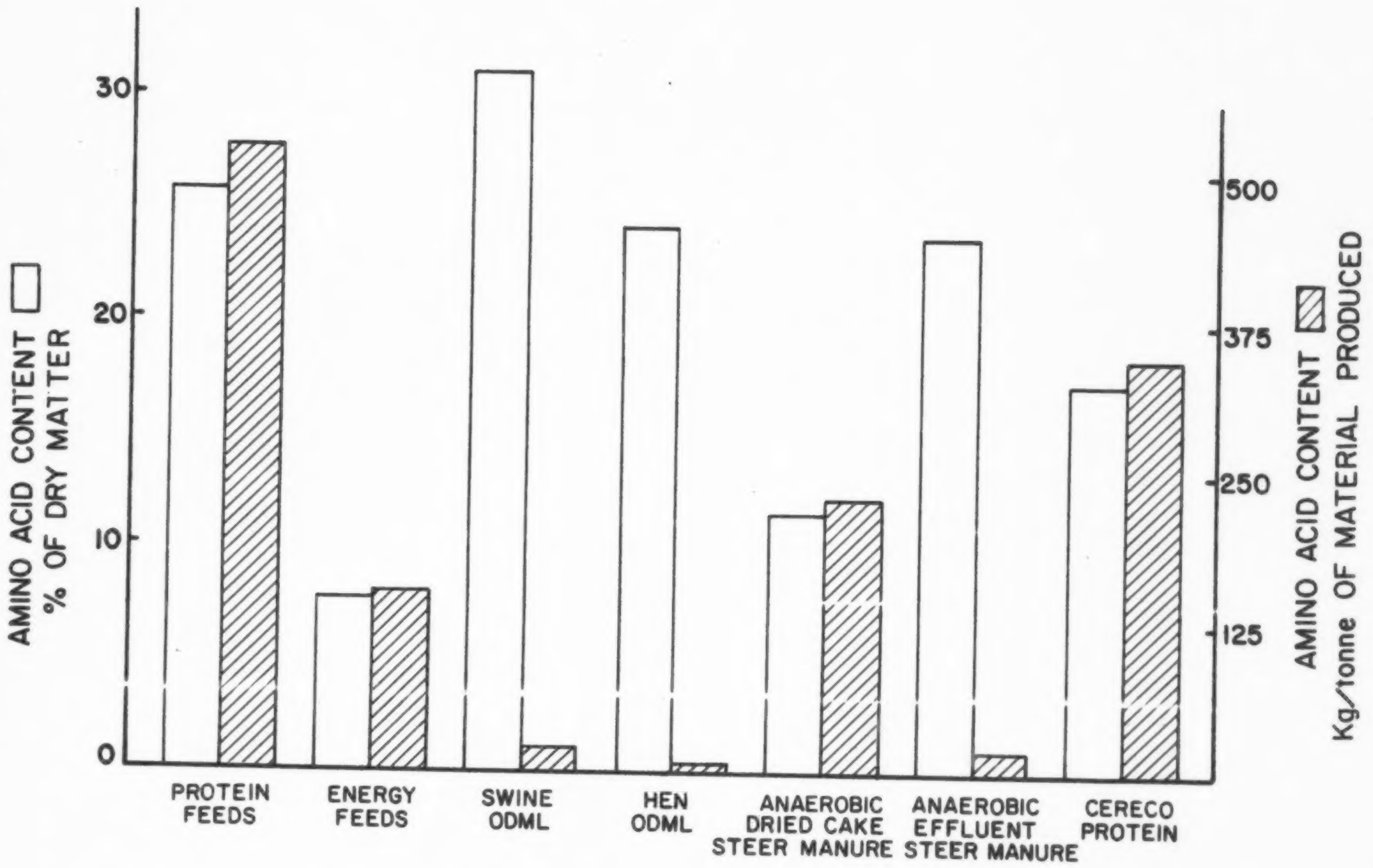

Figure 14. Comparison of Amino Acid Contents for Conventional Feedstuffs and Processed Animal Manures

TABLE 35. A COMPARISON OF THE AMINO ACID CONTENTS OF SOYBEAN MEAL, GROUND CORN, AND AEROBICALLY DIGESTED LAYING HEN AND SWINE MANURES

			Aerobically Stabilized	
Amino Acid, % of Dry Matter	Soybean Meal 44%*	Ground Corn*	Laying Hen Manure†	Swine Manure‡
Alanine	2.76	0.91	1.83	2.83
Arginine §	3.81	0.46	1.70	1.28
Aspartic Acid	7.34	0.23	2.46	3.73
Cystine	0.79	0.11	0.17	n/a
Glutamic Acid	10.46	3.19	3.34	5.06
Glycine	2.74	0	1.57	2.29
Histidine §	1.44	0.23	0.74	0.47
Hydroxyproline	n/a	0.11	n/a	n/a
Isoleucine §	2.77	0.46	1.20	1.49
Leucine §	4.31	1.03	1.86	2.79
Lysine §	3.43	0.23	1.80	1.42
Methionine §	0.67	0.11	0.51	0.77
Phenylalanine §	2.80	0.46	1.17	1.48
Proline	3.28	1.03	1.00	1.29
Serine	2.91	0.11	0.86	2.55
Threonine §	2.22	0.34	1.26	1.96
Tryptophan §	0.66	0.11	n/a	0.28
Tyrosine	1.73	0.46	0.80	1.17
Valine §	2.76	0.34	1.68	2.06
Total Amino Acids	56.88	9.92	23.95	32.92
Essential Amino Acids	24.87	3.77	11.92	14.0
% of Total	43.7	38.0	49.8	42.5

* Atlas of Nutritional Data on United States and Canadian Feeds, 1971

† J. Martin, Jr., Unpublished data (1980)

‡ Harmon *et al.* (1973; 1975)

§ Essential Amino Acids

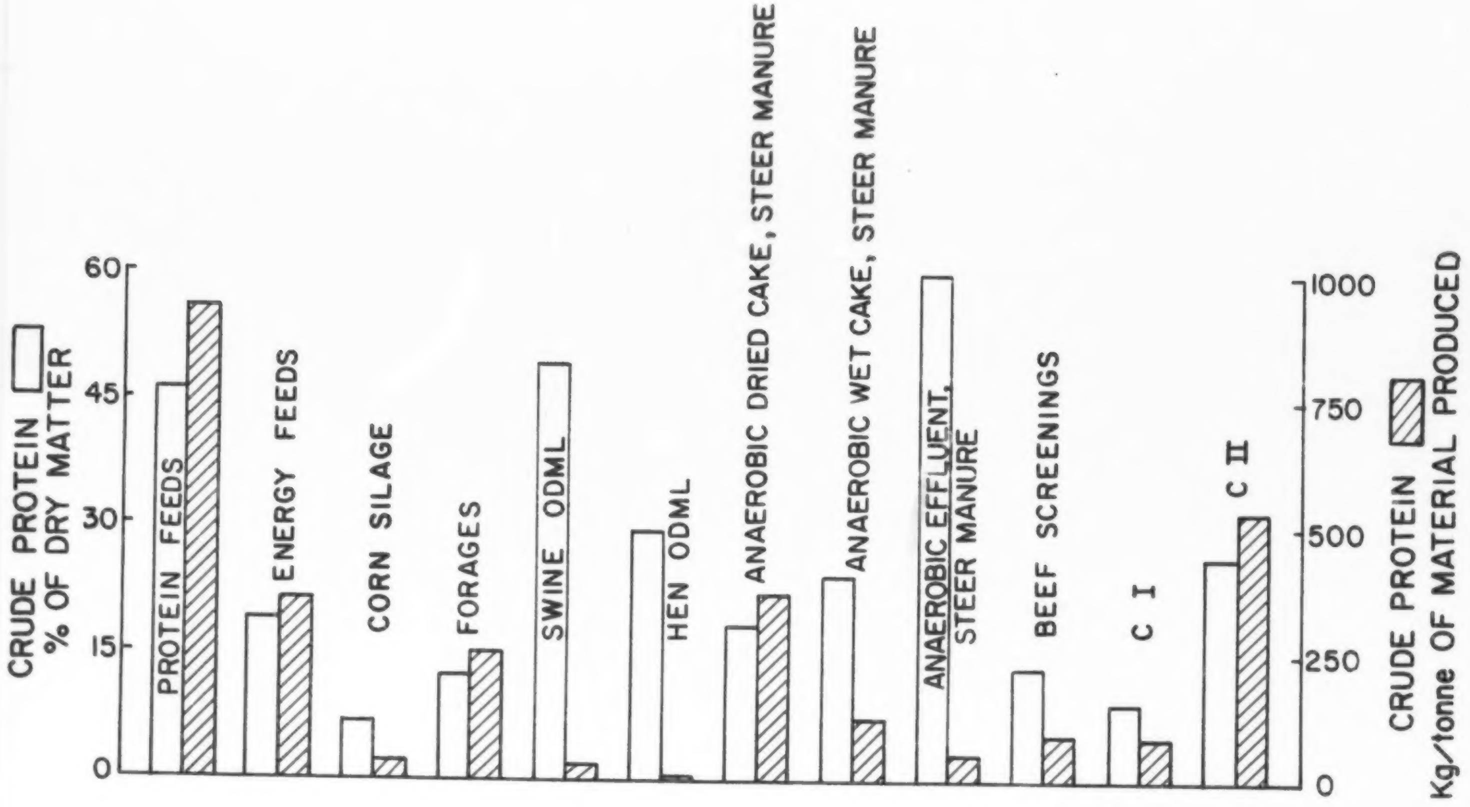

Figure 15. Comparison of Crude Protein Contents for Conventional Feedstuffs and Processed Animal Manures

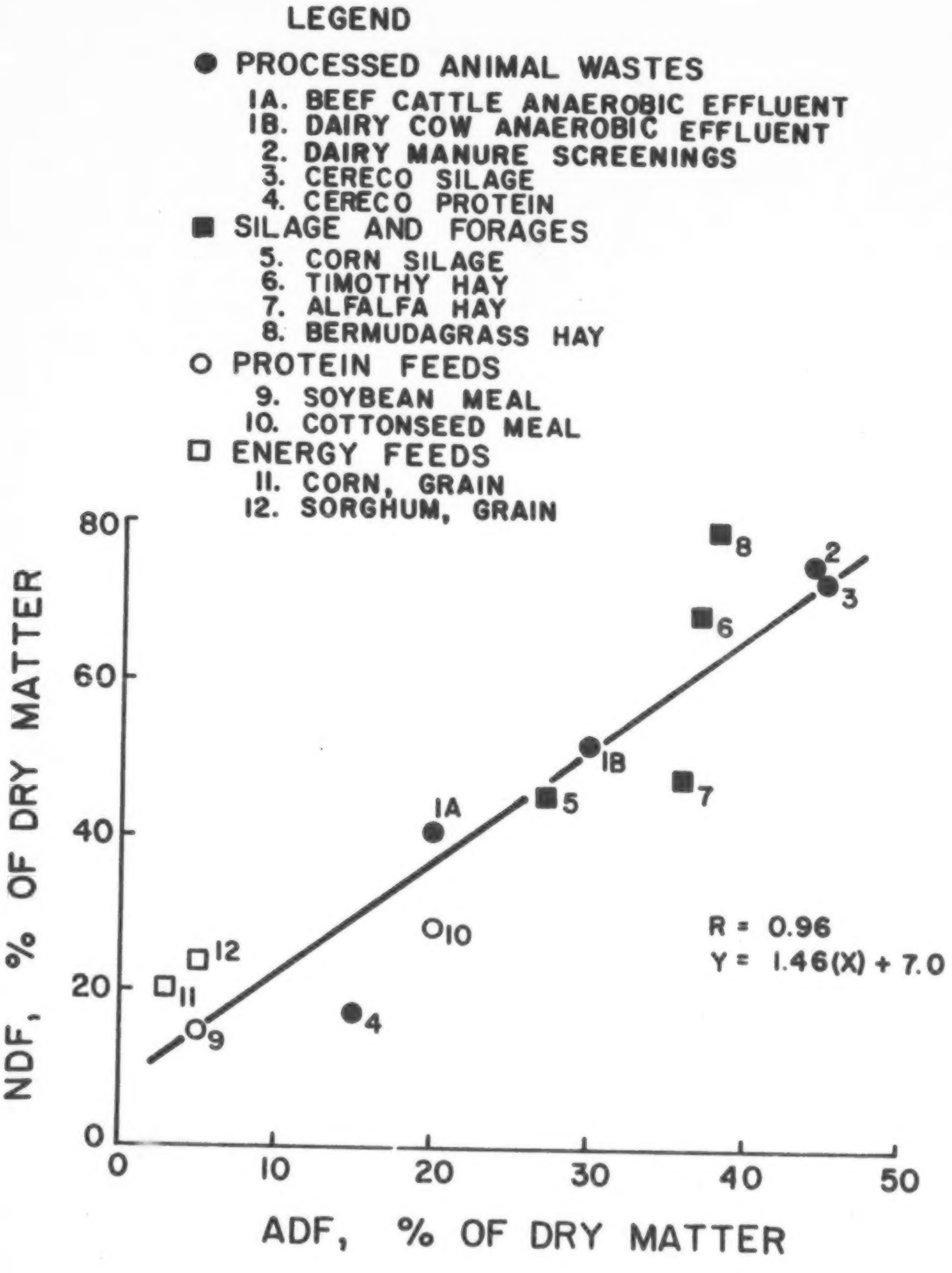

Figure 16. Relationship Between ADF and NDF Content for Conventional Feedstuffs and Processed Animal Manures

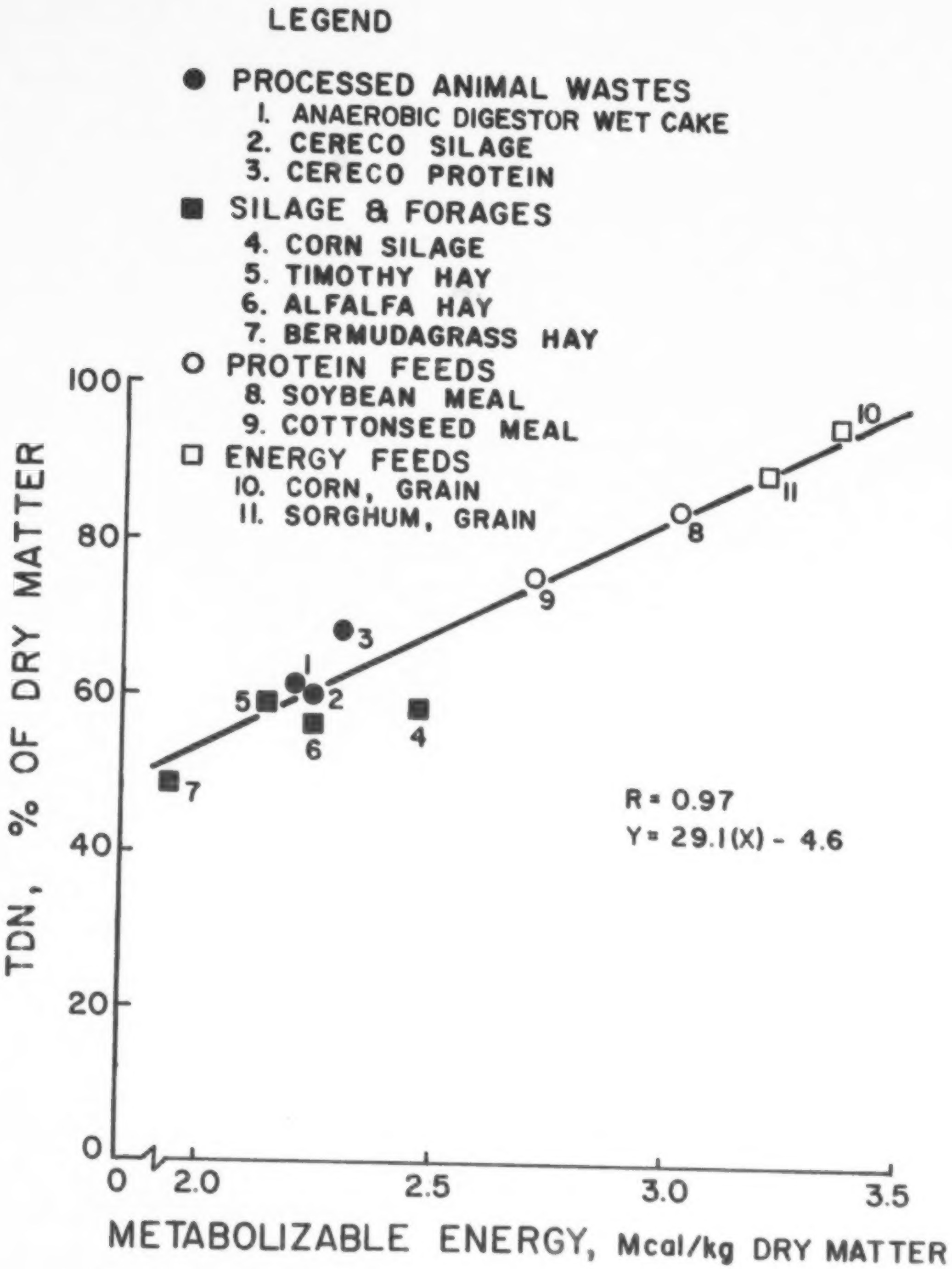

Figure 17. Relationship Between Metabolizable Energy and TDN Content for Conventional Feedstuffs and Processed Animal Manures

$58 per tonne (100% dry matter) when compared to the cost of corn silage.

$80 per tonne (100% dry matter) when compared to the cost of forages.

$24 per tonne (42% dry matter, as processed) when compared to the cost of corn silage.

$34 per tonne (42% dry matter, as processed) when compared to the cost of forages.

Estimation of the economic values of the remaining other processed animal manures in terms of equivalent conventional feedstuffs could not be determined from the existing data.

SECTION 7

NUTRITIVE AND ECONOMIC VALUE OF DRIED POULTRY WASTE (DPW) BASED ON THE RESULTS OF FEEDING TRIALS

INTRODUCTION

Previous sections compared animal manures and processed animal manures to analogous conventional feedstuffs on the basis of their reported nutrient characteristics. Such comparisons do not tell the whole story since they do not identify how the manures are actually digested and utilized by animals. Animal feeding trials do identify the actual utilization of manures as feedstuffs and permit their nutritive and economic values to be determined on the basis of animal productivity (i.e., egg and milk production, body weight gain, etc.).

This section attempts to identify the value of DPW as a feedstuff based upon information from reported feeding trials. An extensive review of the literature was conducted with emphasis placed on the period of 1969 to 1979. Where appropriate, earlier studies also were reviewed and included in the evaluation. A total of 56 studies were identified that involved the direct utilization of DPW as a feedstuff. All of these studies were not utilized in this evaluation. The following criteria were used to select studies appropriate for detailed evaluation:

1. An accurate description of the experimental design was stated.
2. A positive control group was utilized.
3. Feedstuffs utilized in ration formulation were conventional and the percentages utilized were reported.
4. Sufficient animal performance data were reported to enable nutritive evaluation.

The following methodology was used to evaluate the nutritive information in the evaluated studies. If the composition of the rations fed in the various studies was reported in the original study, the data were utilized as presented. If the composition was not reported but International Reference Numbers were reported for the ingredients, the ration composition was calculated using the data given in the Atlas of Nutritional Data on United States and Canadian Feeds (1971). If only the ration ingredients were reported, the ration composition was calculated using the data of Ensminger and Olentine (1978).

As collected manure composition, if reported in the original study, was utilized as presented. If as collected manure composition was not reported, the mean raw waste composition reported in Sections 5 and 6 was utilized to calculate ration composition of diets containing manure.

Animal performance results, if not reported in the original study, were calculated utilizing the following:

$$\text{Feed Efficiency} = \frac{\text{feed consumption per animal per day}}{\text{average daily gain}}$$

$$\text{Average daily gain} = \frac{\text{final body weight - initial body weight}}{\text{trial length}}$$

$$\begin{array}{l}\text{Egg Production per}\\ \text{Unit of time (\%)}\end{array} = \frac{\text{total eggs produced}}{\text{trial length}} \times 100$$

$$\begin{array}{l}\text{Feed consumption}\\ \text{per dozen eggs}\end{array} = \frac{\text{feed intake per day x 12}}{\text{egg production}}$$

$$\text{Total feed consumption} = \begin{array}{l}\text{conventional feedstuffs consumed +}\\ \text{manure consumed}\end{array}$$

$$\text{Total manure consumed} = \begin{array}{l}\text{feed consumption per animal per day x trial}\\ \text{length x percent of manure in ration (on a}\\ \text{dry matter basis)}\end{array}$$

$$\begin{aligned}\text{Body weight gain} &= \text{final body weight - initial body weight or}\\ &= \text{average daily gain x trial length}\end{aligned}$$

$$\begin{array}{l}\text{Feed consumption}\\ \text{per kilogram milk}\end{array} = \frac{\text{feed consumption per cow per day}}{\text{milk production per cow per day}}$$

$$\begin{array}{l}\text{Total eggs or milk}\\ \text{produced}\end{array} = \text{egg or milk production per day x trial length}$$

Initial body weights, if not reported, were estimated from NRC tables, based upon feed intake per day, average daily gain and ration composition (NRC, 1976; 1977; 1978). Age of caged laying hens, if not reported, was estimated based upon production stage as described by Scott et al. (1976).

The following methodology was used to identify the economic costs and benefits associated with the use of DPW as a feedstuff. Feed ingredient costs shown in Appendix E were used to compute total ration costs in the evaluated studies. No cost was assumed for the manure. Ration costs were computed by multiplying the percent of feedstuff in a ration by its cost, summing all ingredient costs and converting to cost per tonne.

Costs were calculated as follows:

Feed costs per animal per day = feed intake per animal per day x ration cost

$$\text{Feed costs per kilogram weight gain.} = \frac{\text{kilograms of feed}}{\text{kilograms body weight}} \times \text{ration cost}$$

Feed costs per dozen eggs = kilograms of feed per dozen eggs x ration cost

Total feed costs = feed cost per animal per day x trial length

Steer costs and selling prices were based upon a market price of $154.32 per 100 kg live body weight (March 1979). Heifer costs and selling prices of $165.35 per 100 kg live body weight (March 1979). Swine costs and selling prices were based upon a market price of $81.50 per kg live body weight (March 1979). The egg selling price was based upon a wholesale price of $0.74 per dozen for washed, candled, graded, cartoned large white eggs (March 1979). This egg price was discounted $0.20 to reflect the price that a producer would receive for unwashed, ungraded, uncandled large white eggs packed in 30 dozen cases.

Revenues were calculated as follows:

Egg sales = total dozens of eggs produced x $0.54

Milk value = total kilograms of milk produced x $0.242 (based on $0.242 per kilogram of milk - March 1979)

Economic return = animal selling price minus animal cost minus total feed cost

The estimates of the gross monetary value of manures listed as feedstuffs was based on the difference between the economic returns in terms of dollars, for: a) the control diet which contained no manure, and b) the experimental diets or rations which contained manure. This difference was then divided by the quantity of manure consumed to the gross monetary value determined, dollars per tonne of manure consumed. As previously noted, it was assumed in calculations of feed costs that manure had no cost.

In the past, the gross value of animal manures has been calculated on the basis of feed cost savings only. This practice is misleading. Calculating the gross value of animal manures on the basis of differences in economic returns and relating this to the amount of manure consumed is a better method because it reflects actual animal performance.

The theoretical response of manure ration content, expressed as a percentage of the control, is shown in Figure 18. If the nutrient value of the manure is greater than the nutrient value of the feedstuff replaced, there should be an increase in animal performance, such as egg production, milk production, weight gain, etc. If the nutrient value of the manure is equal to that of the feedstuff replaced, there should be no change in animal performance; and if the nutrient value of the manure is lower than the feedstuff replaced, animal performance should decrease.

In most of the evaluated feeding trials, more than one feedstuff was replaced by manure. In addition, the replaced feedstuffs were not the analogous feedstuffs indicated in Sections 5 and 6. The actual animal response also is confounded by interactions between the ration metabolizable energy, protein and minerals, which become critical as the manure content increases. Therefore, the actual animal performance response of manures used as feedstuffs may be more like that shown in Figure 19. Animal performance may increase if the nutrient content of the manure is greater than the nutrient value of the feedstuff replaced. However, as the manure content increases, the metabolizable energy and/or protein content of the ration becomes limited, the mineral content increases, and animal performance will decrease.

In this report, the determination of "optimum" and maximum levels of incorporating manure into a ration is based upon a graphical presentation of the feeding trial results and a calculation of a linear regression of what appeared to be the straight line portion of the results (Figure 19). The identified maximum level of incorporation, statistically, was where the regression line crossed the "x" axis; nutritionally, it is the level that will neither enhance or adversely affect animal performance as compared to the controls. In all subsequent figures, regression equations using the actual reported data were used to identify the maximum level.

The "optimum" level is the manure ration content that would provide the highest level of animal performance. If enough data were available, the "optimum" level would be readily and accurately defined. However, in most feeding trials only limited data were available and the identified "optimum" level is a subjective estimate made by the authors.

A summary of the evaluated feeding trials, the composition of the diets and manure utilized in these studies, and methods of handling or processing the manure prior to feeding is presented in Appendix G.

DPW FED TO LAYING HENS

The utilization of dried poultry waste (DPW) as a feedstuff to laying

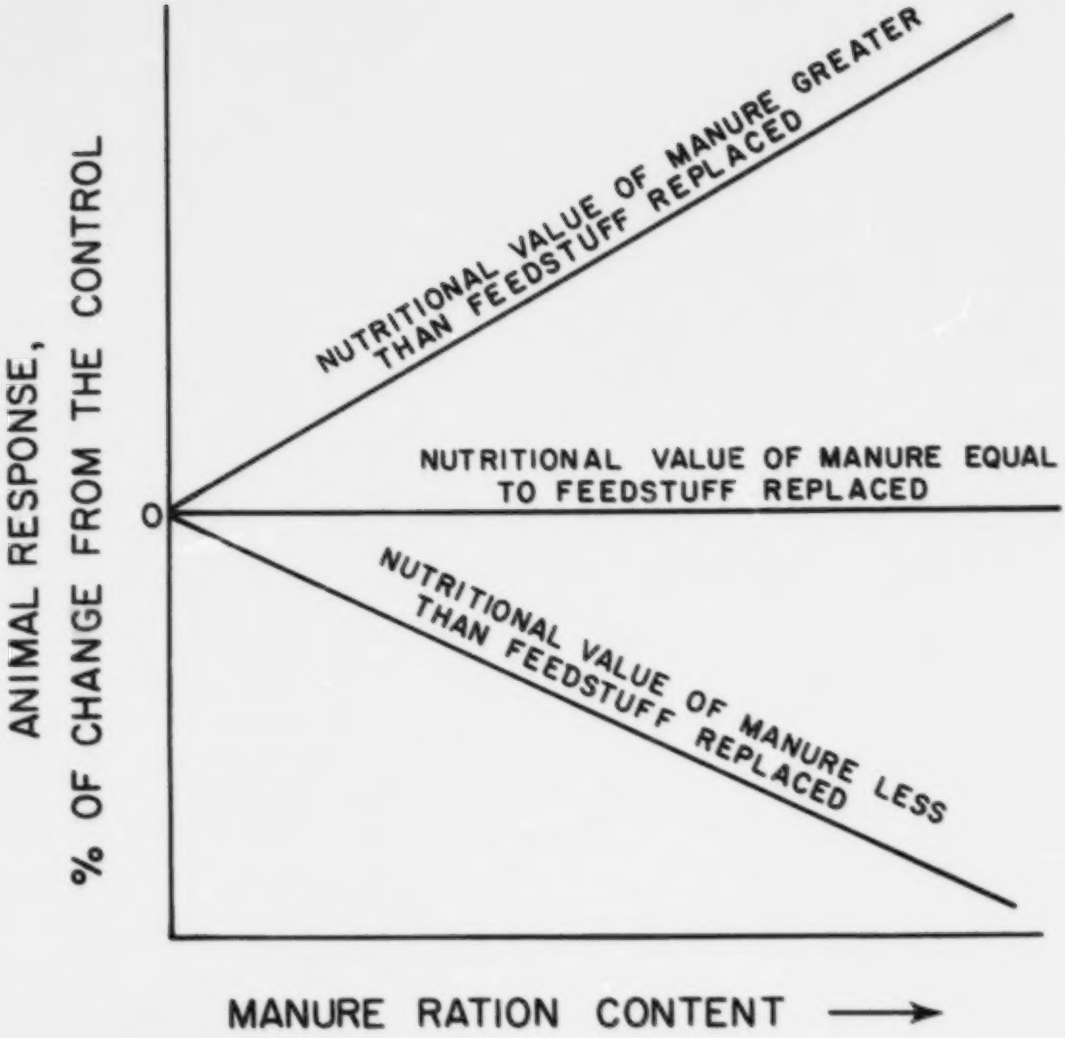

Figure 18. Theoretical Animal Response When Animal Manures Are Used as Substitutes for Conventional Feedstuffs

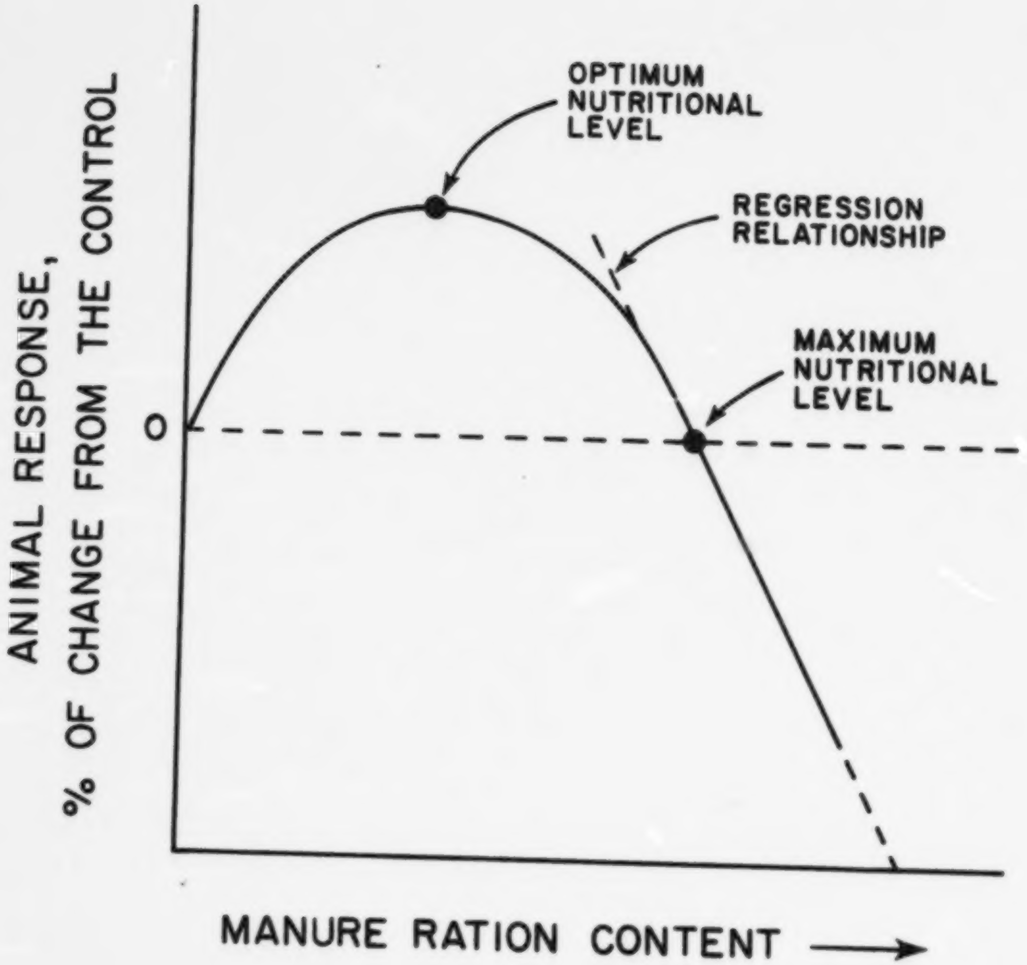

Figure 19. Actual Animal Response When Animal Manures Are Used as Substitutes For Conventional Feedstuffs

hens has been investigated in 23 studies. Only nine studies fulfilled the selection criteria and were evaluated (Appendix G, Table G-1). In these nine studies, DPW was utilized as a substitute for: (a) an energy feed (corn); (b) protein and energy feeds (soybean meal and corn or sorghum); or (c) a percentage of all control diet ingredients, with or without energy supplementation utilizing lard or soybean oil.

The composition of the control and DPW diets is shown in Table G-2. The composition of DPW and the sources and methods of dehydration are shown in Tables G-3 and G-4. The crude protein content of the DPW diets was believed to not accurately reflect the availability of nitrogen in the diet (Swanson, 1975); therefore, the "available protein content" was calculated using the amino acid content of DPW (10.23% dry matter basis). When DPW was utilized as a substitute for protein or energy feeds, both the available protein and metabolizable energy levels of the diets decreased in a direct relationship with DPW diet content. However, when DPW was utilized as a substitute for a portion of the diet and the resultant diet was supplemented with lard or soybean oil, only the available protein content decreased in a direct relationship with DPW content.

The performance of laying hens fed various levels of DPW should be predictable by utilizing the composition of the diets (Table G-2). It can be hypothesized that as the diet metabolizable energy (ME) levels, available protein levels (P) and the ME/P ratios decrease, feed consumption will increase, and efficiency, productivity and economic benefits will decrease in a direct relationship with DPW content.

Animal Performance Evaluation

The performance of laying hens (feed consumption per day, per dozen eggs, total feed consumed, and egg production) fed DPW as a feedstuff is shown in Table 36. Some of these results are expressed as a percent change from the control and are shown in Table 37.

The effects of substituting 12.5 and 25% DPW or 22.5% DPW for similar amounts of corn in the basal diets were investigated by Flegal *et al*. (1972) and Nesheim (1972). All feed consumption parameters increased and productivity decreased in the studies feeding 22.5 and 25% DPW. Conversely, hens fed 12.5% DPW decreased feed consumption and increased productivity. The poor performance of the 22.5 and 25% DPW fed hens might be related to their decreased dietary metabolizable energy levels (Table G-2).

The effects of utilizing 10 to 40% DPW as a substitute for soybean meal and corn or sorghum grain in the basal diets were investigated by Quisenberry and Bradley (1969), Flegal and Zindel (1970; 1971) and Biely *et al*. (1972). Evaluation of these investigations is confounded because of conflicting animal performance when similar levels of DPW were fed. Generally, the feed consumption per day and total feed consumed of the 10% DPW hens was comparable to that of controls. However, feed consumption per dozen eggs decreased because of the increased egg production of the DPW fed birds. Increasing the DPW content to 20% resulted in all feed consumption parameters increasing, while productivity was variable. Increasing the

TABLE 36. PERFORMANCE OF LAYING HENS FED DPW AS A FEEDSTUFF

		Kilograms					
Source	Diet	Feed consumption per hen-day	Feed consumption per doz eggs	Total feed consumption	Total DPW consumed	Egg production (%H-D)	Total eggs produced (dozens)
Quisenberry and Bradley (1969)	Control	0.106	1.752	35.616	-	72.3	20.244
	10% DPW	0.105	1.657	35.280	3.528	76.3	21.364
	20% DPW	0.109	1.806	36.624	7.325	72.6	20.328
Flegal and Zindel (1970)	Control	0.113	2.110	15.707	-	64.0	7.413
	10% DPW	0.113	1.910	15.707	1.571	71.1	8.236
	20% DPW	0.119	2.080	16.541	3.308	68.7	7.958
	30% DPW	0.124	2.460	17.236	5.171	60.3	6.985
Flegal and Zindel (1971)	Control	0.105	1.952	38.430	-	64.7	19.733
	10% DPW	0.107	1.961	39.162	3.916	65.4	19.947
	20% DPW	0.109	2.084	39.894	7.979	62.8	19.154
	40% DPW	0.111	2.347	40.626	16.250	57.0	17.385
Hodgetts (1971)	Control	0.131	2.894	47.815	-	54.4	16.547
	10.45% DPW	0.124	2.700	45.260	4.730	54.9	16.700
Pisone and Begin (1971)	Control	0.118	2.017	26.432	-	70.2	13.104
	5% DPW + lard	0.125	2.027	28.000	1.400	74.0	13.813
	10% DPW + lard	0.117	1.983	26.208	2.621	70.8	13.216
	20% DPW + lard	0.112	2.021	25.088	5.018	66.5	12.413
	30° DPW + lard	0.119	2.159	26.656	7.997	66.1	12.339

(continued)

TABLE 36. (continued)

Source	Diet	Kilograms				Egg production (%H-D)	Total eggs produced (dozens)
		Feed consumption per hen-day	Feed consumption per doz eggs	Total feed consumption	Total DPW consumed		
Flegal *et al.* (1972)	Control	0.096	1.796	39.552	-	64.4	22.111
	12.5% DPW	0.095	1.683	39.140	4.892	67.8	23.278
	25% DPW	0.108	1.990	44.496	11.124	65.0	22.317
Biely *et al.* (1972)	Control	0.112	1.780	11.200	-	75.6	6.300
	25% DPW	0.151	2.500	15.100	1.510	72.4	6.033
Nesheim (1972)	Control	0.104	1.360	8.008	-	91.7	5.884
	22.5% DPW	0.118	1.620	9.086	2.044	89.0	5.711
Trackulchang and Balloun (1975)	Control	0.101	1.750	15.150	-	69.2	8.650
	12.5% DPW + SBO*	0.099	1.782	14.850	1.856	66.8	8.350
	25% DPW + SBO*	0.097	1.838	14.550	3.638	63.4	7.925

* Soybean oil

TABLE 37. PERFORMANCE OF LAYING HENS FED DPW AS A FEEDSTUFF (percent change from the control)

Source	Diet	Feed Consumption Per Hen-Day and Total Feed Consumed	Feed Consumption Per Dozen Eggs	Percent Egg Production and Total Dozens of Eggs Produced
Quisenberry and Bradley (1969)	10% DPW	- 0.9	- 5.4	+ 5.5
	20% DPW	+ 2.8	+ 3.1	+ 0.4
Flegal and Zindel (1970)	10% DPW	0	- 9.5	+11.1
	20% DPW	+ 5.3	- 1.4	+ 7.3
	30% DPW	+ 9.7	+16.6	- 5.8
Flegal and Zindel (1971)	10% DPW	+ 1.9	+ 0.5	+ 1.1
	20% DPW	+ 3.8	+ 6.8	- 2.9
	40% DPW	+ 5.7	+20.2	-11.9
Hodgetts (1971)	10.45% DPW	- 5.3	- 6.7	+ 0.9
Pisone and Begin (1971)	5% DPW & Lard	+ 5.9	+ 0.5	+ 5.4
	10% DPW & Lard	- 0.8	- 1.7	+ 0.9
	20% DPW & Lard	- 5.1	+ 0.2	- 5.3
	30% DPW & Lard	+ 0.8	+ 7.0	- 5.8
Flegal et al. (1972)	12.5% DPW	- 1.0	- 6.3	+ 5.3
	25% DPW	+12.5	+10.8	+ 0.9
Biely et al. (1972)	25% DPW	+34.8	+40.4	- 4.2
Nesheim (1972)	22.5% DPW	+13.5	+19.1	- 2.9
Trackulchang and Balloun (1975)	12.5% DPW & SBO*	- 2.0	+ 1.8	- 3.5
	25% DPW & SBO*	- 4.0	+ 5.0	- 8.4

*Soybean oil

DPW content further (25, 30, and 40%) resulted in increased feed consumption and decreased productivity. The poor performance of the laying hens fed diets containing 20 to 40% DPW might be related to their reduced dietary metabolizable energy levels.

The influence of substituting all dietary ingredients with 5 to 30% DPW and equalizing dietary metabolizable energy levels by lard or soybean oil supplementation was investigated by Pisone and Begin (1971) and Trackulchang and Balloun (1975). Feed consumption per hen-day for all DPW fed birds was generally comparable to that of controls. However, efficiency and productivity decreased in a direct relationship with increasing DPW content. The poor performance by hens fed high levels of DPW might be related to their decreased dietary available protein contents (Table G-2).

The effect of substituting 10.5% DPW for a similar content of all dietary ingredients (without energy supplementation) was investigated by Hodgetts (1971). All feed consumption parameters decreased and productivity increased for the DPW fed birds. The metabolizable energy content of the DPW diet was slightly lower than the control diet (Table G-2). However, this did not adversely affect bird performance.

The animal performance evaluation of utilizing DPW as a feedstuff for laying hens revealed interesting correlations. When DPW is substituted for typical feedstuffs, the maximum level of incorporation that will not adversely affect productivity and efficiency is about 20 and 13.7%, respectively (Figure 20). Supplementing DPW diets with lard or soybean oil reduces the maximum levels of incorporation of DPW that will not adversely affect productivity and efficiency to about 9.75 and 10.75%, respectively (Figure 21).

Economic Value Estimation

The economic estimation of the value of DPW as a feedstuff for laying hens (based on feed costs, revenue from egg sales, and economic return) is shown in Table 38. Some of these economic results are expressed as a percent change from the controls in Table 39.

Studies substituting DPW for energy and/or protein feedstuffs (i.e., corn and soybean meal) or for a percentage of all basal ingredients were evaluated together because of their similar animal performance results (Quisenberry and Bradley, 1969; Flegal and Zindel, 1970, 1971; Hodgetts, 1971; Flegal *et al*., 1972; Nesheim, 1972; Biely *et al*., 1972). Feed costs per hen-day and per dozen eggs decreased when DPW was incorporated into the various laying hen diets. However, the magnitudes of the reductions were not similar to the reductions in ration costs per tonne. This difference is attributed to increased feed consumption and decreased productivity as the dietary DPW content increased. Generally, when DPW content was 10-12.5%, all feed costs were similarly reduced. However, when DPW content was greater than 12.5%, decreases in feed costs per hen-day and per dozen eggs were less than the decreases in ration cost per tonne.

Typically, a dietary DPW content of 10-12.5% resulted in increased egg production and projected revenue from egg sales as compared to control

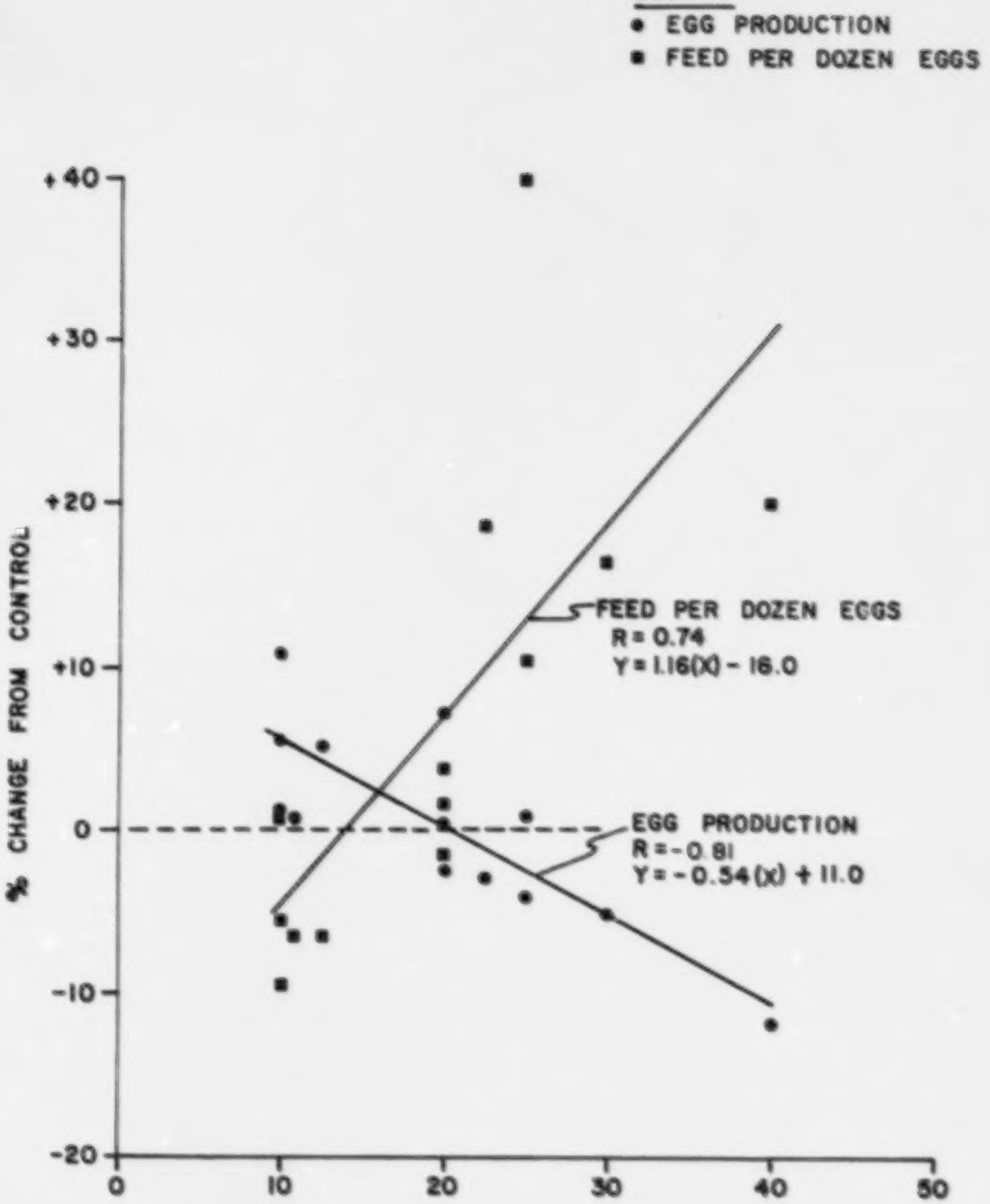

Figure 20. Relationships Between DPW Diet Content (without lard or soybean oil supplementation), Feed Consumption Per Dozen Eggs, and Egg Production For Laying Hens Fed DPW

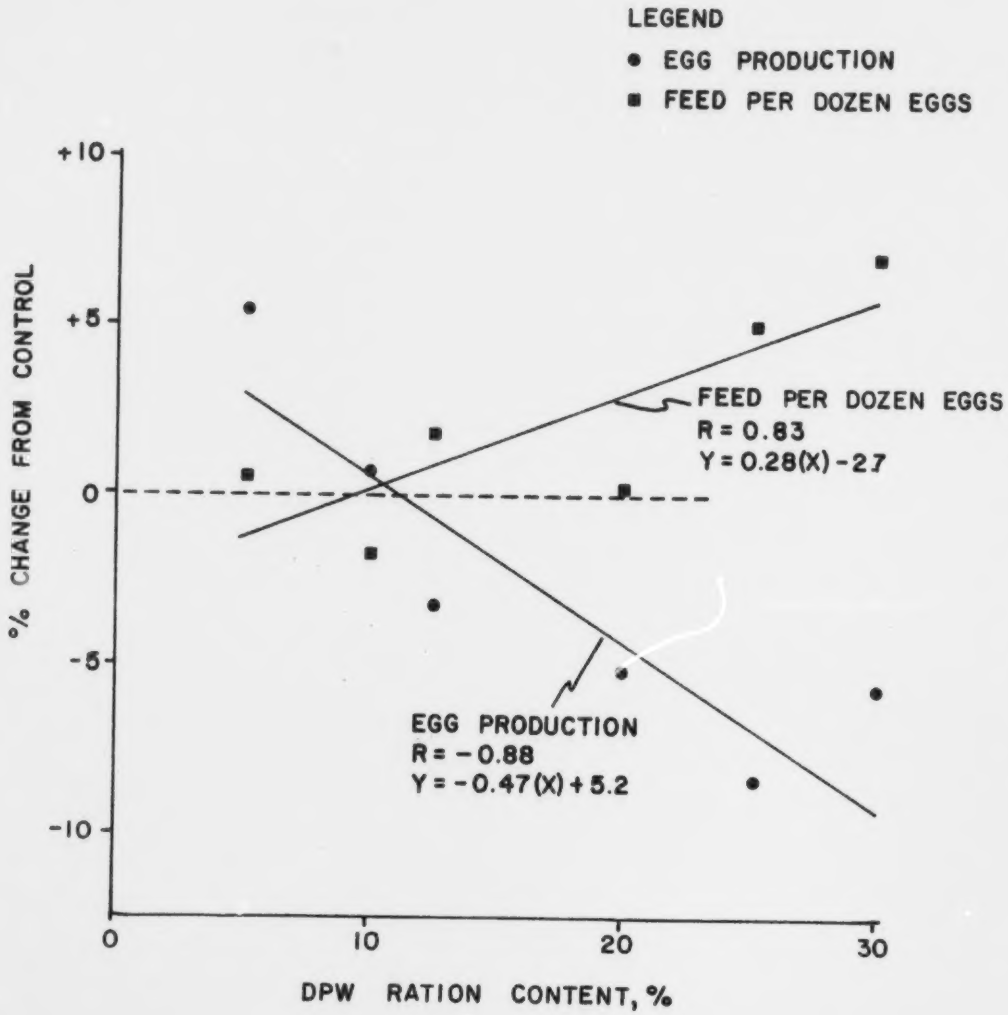

Figure 21. Relationships Between DPW Diet Content(with lard or soybean oil supplementation), Feed Consumption Per Dozen Eggs, and Egg Production For Laying Hens Fed DPW

TABLE 38. ECONOMIC ESTIMATE OF THE VALUE OF DPW AS A FEEDSTUFF FOR LAYING HENS (dollar)

Source	Diet	Ration Cost Per Tonne	Feed Cost Per H-D†	Feed Cost Per Dozen Eggs	Total Feed Cost	Revenue From Egg Sales	Economic Return	Gross Value per Tonne of DPW
Quisenberry and Bradley (1969)	Control	122.80	.0130	0.2152	4.368	10.93	6.56	-
	10% DPW	107.40	.0113	0.1780	3.797	11.54	7.74	334.47
	20% DPW	92.10	.0100	0.1664	3.360	10.98	7.62	144.71
Flegal and Zindel (1970)	Control	134.60	.0152	0.2840	2.113	4.00	1.89	-
	10% DPW	120.02	.0136	0.2292	1.890	4.45	2.56	426.48
	20% DPW	109.50	.0130	0.2278	1.807	4.30	2.49	181.38
	30% DPW	99.00	.0123	0.2435	1.710	3.77	2.06	32.88
Flegal and Zindel (1971)	Control	137.20	.0144	0.2678	5.270	10.66	5.39	-
	10% DPW	123.50	.0132	0.2422	4.831	10.77	5.94	140.45
	20% DPW	113.10	.0123	0.2357	4.502	10.34	5.84	56.40
	40% DPW	90.90	.0101	0.2133	3.697	9.39	5.69	18.46
Hodgetts (1971)	Control	130.10	.0170	0.3765	6.205	8.94	2.73	-
	10.45% DPW	116.50	.0144	0.3146	5.256	9.02	3.76	217.76
Pisone and Begin (1971)	Control	132.30	.0156	0.2668	3.494	7.08	3.59	-
	5% DPW & Lard	128.80	.0161	0.2611	3.606	7.46	3.85	185.71
	10% DPW & Lard	125.60	.0147	0.2491	3.293	7.14	3.85	99.20
	20% DPW & Lard	122.10	.0137	0.2468	3.069	6.70	3.63	7.97
	30% DPW & Lard	118.90	.0141	0.2567	3.158	6.66	3.57	- 2.50

continued

TABLE 38. (continued)

Source	Diet	Ration Cost Per Tonne	Feed Cost Per H-D †	Feed Cost Per Dozen Eggs	Total Feed Cost	Revenue From Egg Sales	Economic Return	Gross Value DPW/Tonne
Flegal *et al.* (1972)	Control	134.90	.0130	0.2423	5.356	11.94	6.58	-
	12.5% DPW	121.60	.0116	0.2047	4.779	12.57	7.79	247.34
	25% DPW	108.30	.0117	0.2155	4.820	12.05	7.23	58.43
Biely *et al.* (1972)	Control	139.10	.0156	0.2476	1.56	3.47	1.91	-
	25% DPW	98.40	.0149	0.2460	1.49	3.26	1.77	- 92.72
Nesheim (1972)	Control	131.90	.0137	0.1794	1.055	3.18	2.12	-
	22.5% DPW	103.90	.0123	0.1683	0.947	3.08	2.13	4.89
Trackulchang and Balloun (1975)	Control	137.50	.0139	0.2406	2.085	4.67	2.58	-
	12.5% DPW & SBO*	132.10	.0131	0.2354	1.965	4.58	2.61	16.16
	25% DPW & SBO*	126.70	.0123	0.2329	1.845	4.28	2.43	- 41.23

*Soybean oil

† H-D = Hen Days

TABLE 39. ECONOMIC ESTIMATE OF THE VALUE OF DPW AS A FEEDSTUFF FOR LAYING HENS
(Percent change from the control)

Source	Diet	Feed Cost Per Tonne	Feed Cost Per Hen-Day and Total Feed Costs	Feed Costs Per Dozen Eggs	Revenue From Egg Sales	Economic Return
Quisenberry and Bradley (1969)	10% DPW	-12.5	-13.1	-17.3	+ 5.6	+18.0
	20% DPW	-25.0	-23.1	-22.7	+ 0.4	+16.2
Flegal and Zindel (1970)	10% DPW	-10.8	-10.5	-19.3	+11.2	+35.4
	20% DPW	-18.6	-14.5	-19.8	+ 7.5	+31.7
	30% DPW	-26.4	-19.1	-14.3	- 5.7	+ 9.0
Flegal and Zindel (1971)	10% DPW	-10.0	- 8.3	- 9.6	+ 1.0	+10.2
	20% DPW	-17.6	-14.6	-12.0	- 3.0	+ 8.3
	40% DPW	-33.7	-29.9	-20.4	-11.9	+ 5.6
Hodgetts (1971)	10.45% DPW	-10.4	-15.3	-16.4	+ 0.9	+37.7
Pisone and Begin (1971)	5% DPW & Lard	- 2.6	+ 3.2	- 2.1	+ 5.4	+ 7.2
	10% DPW & Lard	- 5.1	- 5.8	- 6.6	+ 0.8	+ 7.2
	20% DPW & Lard	- 7.7	-12.2	- 7.5	- 5.4	+ 1.1
	30% DPW & Lard	-10.1	- 9.6	- 3.8	- 5.9	- 0.6
Flegal *et al*. (1972)	12.5% DPW	- 9.9	-10.8	-15.5	+ 5.3	+18.4
	25% DPW	-19.7	-10.0	-11.1	+ 0.9	+ 9.9
Biely *et al* (1972)	25% DPW	-29.3	- 4.5	- 0.6	- 6.1	- 7.3
Nesheim (1972)	22.5% DPW	-21.2	-10.2	- 6.2	- 3.1	- 0.5
Trackulchang and Balloun (1975)	12.5% DPW & SBO*	- 3.9	- 5.8	- 2.2	- 1.9	+ 1.2
	25% DPW & SBO*	- 7.9	-11.5	- 3.2	- 8.4	- 5.8

*Soybean oil

groups. As diet DPW content increased beyond this level, egg production and projected revenue decreased significantly (R=-0.80) as DPW content increased. At dietary DPW levels of 20% or more projected revenues from egg sales were generally less than those for controls.

The economic return, which accurately reflects feed costs and productivity, similarly decreased as DPW content increased. The increased economic return for the birds fed 10-12.5% DPW reflects both feed cost savings and increased revenue from egg sales, whereas the increased returns for the 20% DPW groups generally reflects feed cost savings. The diminished economic return for DPW diets containing more than 20% DPW reflects feed cost savings only, which were largely offset by reductions in revenues from egg sales.

The gross estimated value of DPW decreased (R = -0.85) as the DPW content increased. This value is highest for the 10-12.5% DPW diets ($279.79). However there is considerable variation in the individual gross values ($140.45 to $426.48). Increasing the DPW diet content to 20% diminished the gross value ($127.50), and when diet content exceeded 20%, the gross value became minimal ($3.24).

The supplementation of DPW diets with lard or soybean oil (Pisone and Begin, 1971; Trackulchang and Balloun, 1975) reduced all feed cost parameters, but to a lesser degree than unsupplemented DPW diets. This difference is attributed to the high costs of lard and soybean oil ($408.96 and $655.88 per tonne, respectively). Results of the economic assessment of supplemented DPW diets are comparable to unsupplemented DPW diets previously evaluated. The maximum level of incorporating supplemented DPW into laying hen rations, however, is 10% rather than the 10-12.5% level for unsupplemented DPW diets.

This economic assessment of the practice of utilizing DPW as a feedstuff for laying hens has revealed several correlations. When DPW (without lard or soybean oil supplementation) is substituted for typical feedstuff in a laying hen ration, the maximum level of DPW incorporation that will not adversely affect egg revenues is 20% and for supplemented DPW diets the maximum level is about 16% (Figure 22). Similarly, when DPW is added to laying diets without lard or soybean oil supplementation, the maximum level of incorporation that will adversely affect the economic return is about 35%, and for supplemented DPW diets the maximum level is about 16% (Figure 23). Therefore, the maximum economic level of incorporating DPW into unsupplemented laying hens diets is 20-35%, and 12-16% for supplemented diets.

Discussion

This evaluation of animal performance indicates that DPW is not of value as a protein or energy supplement in laying hen diets, especially when it is incorporated at high levels. DPW could be considered as a source of calcium and phosphorus, and possibly some amino acids, but this is highly dependent upon what conventional feedstuff is replaced. The maximum animal response level of incorporating DPW into laying hen diets is about 20%, which is similar to the 20-25% levels reported by Ousterhout and Presser (1971), Young and Nesheim (1972) and Blair (1974). The "optimum"

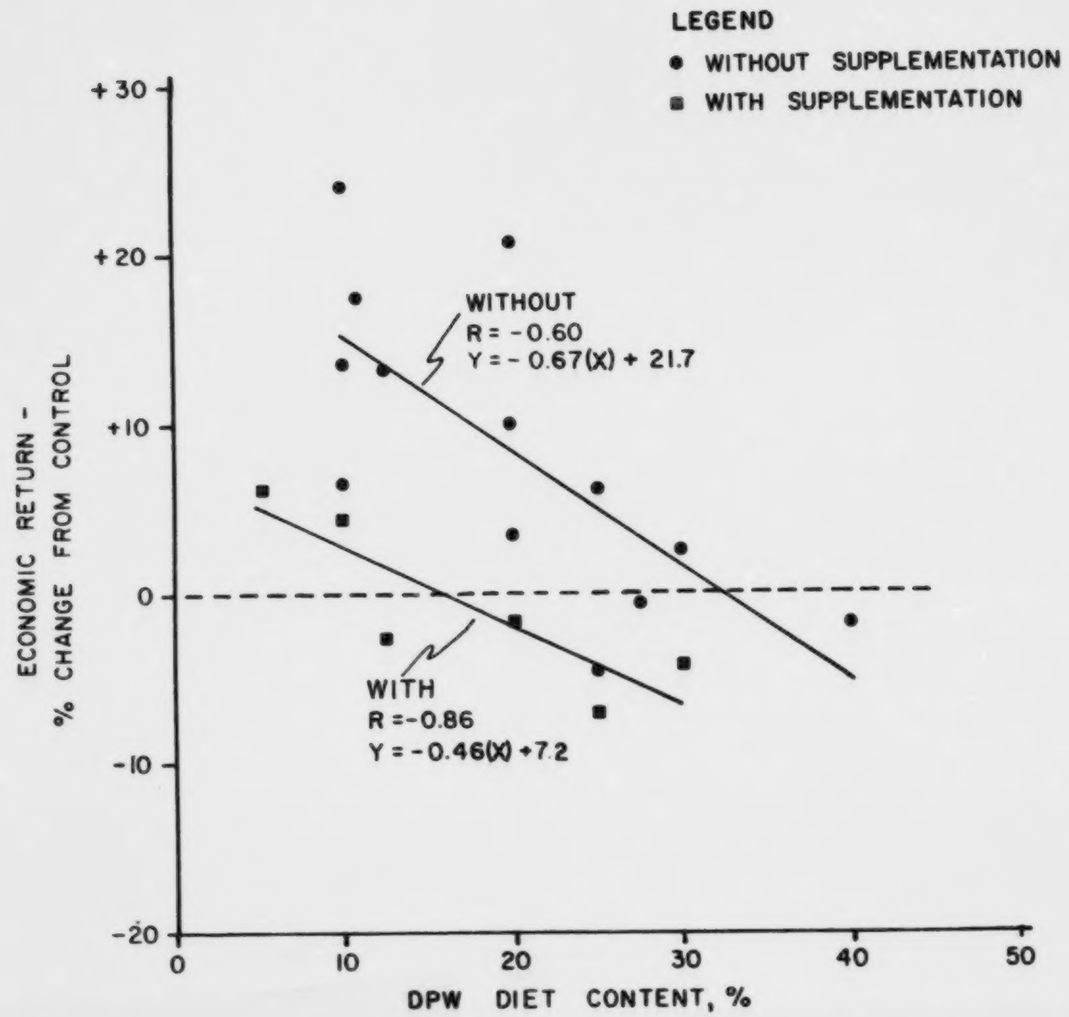

Figure 22. Relationship Between DPW Diet Content and Revenue From Egg Sales For Laying Hens Fed DPW

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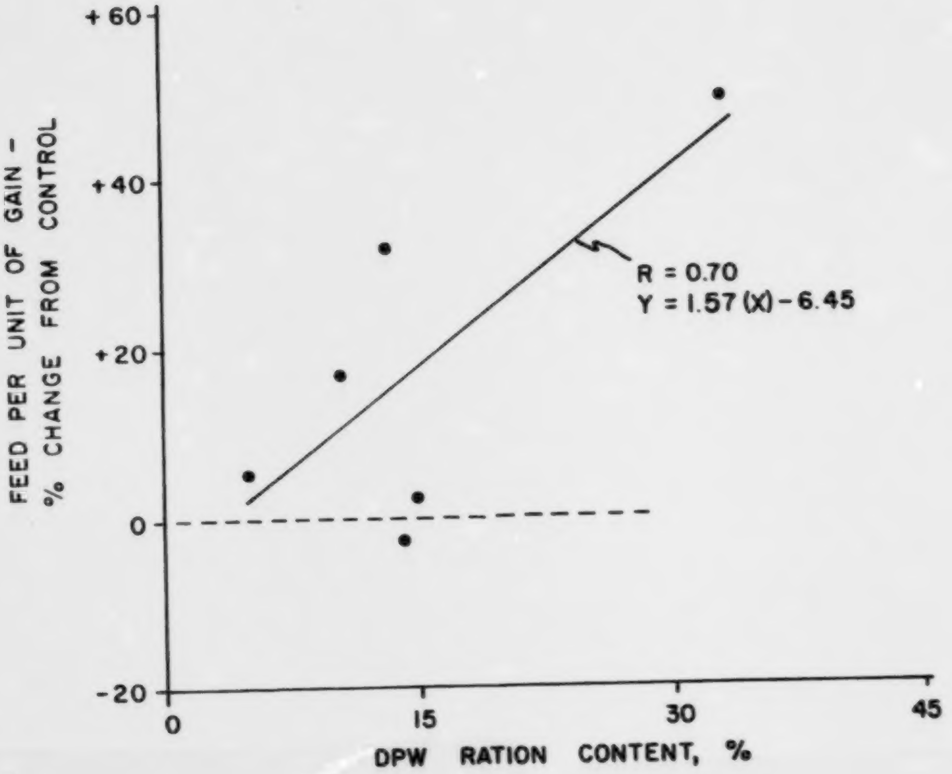

Figure 25. Relationship Between DPW Diet Content and Economic Return for Laying Hens Fed DPW

animal response level is about 10-12.5%.

The economic assessment of utilizing DPW as a feedstuff in laying hen diets clearly indicates the fallacy of estimating the value of animal manures based upon savings in diet costs, because such estimates do not reflect differences in animal performance. Calculating the value of animal manures on the basis of differences in economic returns and relating this to the amount of manure consumed is a better method because it reflects actual animal performance. The maximum economic level of incorporating DPW into laying hen diets is about 20-35%. The "optimum" economic level may be the same as the "optimum" animal response level (10-12.5%), on the basis of calculated gross value of DPW at those levels (Table 40).

TABLE 40. MAXIMUM AND OPTIMUM LEVELS OF INCORPORATING DPW INTO LAYING HEN DIETS

Manure	Maximum Animal Response Level, % *	"Optimum" Animal Response Level, % *	Maximum Economic Level, % †	"Optimum" Economic Level, % †
DPW	14-20	10-12.5	20-35	10-12.5
DPW & Supplementation ‡	8-11	5	16	5

* Figures 20 and 21
† Figures 22 and 23
‡ Lard or soybean oil

The gross value of DPW does not reflect its actual value because collection, storage, processing (drying), transportation, mixing and marketing costs must be subtracted. The actual value of DPW as a feedstuff to laying hens is much lower than the gross value. Forsht _et_ _al_. (1974) estimated the actual value to be $21-35 per tonne, depending upon geographical location, and Quisenberry and Bradley (1969) estimated the actual value to be $80 per tonne when utilized at the 10% level. The calculated gross values of DPW probably do not reflect its value today. Formulation of laying hen diets has changed in the past decade.

DPW FED TO STEERS

Feeding DPW to ruminants has been a subject of interest for several years because of the ability of ruminants to utilize undigested nutrients from the waste of monogastrics. DPW has been utilized as a protein supplement for growing and wintering cattle, and as a protein source for finishing cattle. This section evaluates the feeding of DPW to growing and finishing steers.

The utilization of DPW as a feedstuff to growing and finishing steers has been investigated in 15 studies. Only five studies fulfilled the selection criteria and were evaluated (Table G-5). In the evaluated studies, DPW was utilized as a substitute for: (1) a protein feed (soybean meal); (2) protein and energy feeds (soybean meal and corn); or (3) a percentage of all control diet ingredients.

The composition of the rations utilized in the studies is shown in Table G-6. The crude protein content of rations containing DPW was believed not to accurately reflect nitrogen availability; therefore, digestible protein levels were calculated using the digestible protein content of DPW as 12.6% (Section 5). The incorporation of DPW into rations for growing and finishing steers generally resulted in a decrease in digestible protein, metabolizable energy, ether extract and TDN, and an increase in ash, calcium and phosphorus content. The composition of DPW utilized in the evaluated studies, and sources and methods of dehydration are shown in Tables G-7 and G-8. The extreme range in protein and ash content should be noted and is further evidence that the composition of DPW should be determined for each study prior to initiation of a feeding trial.

Animal Performance Evaluation

The performance of finishing steers (initial and final body weight, weight gain, average daily gain and feed consumption) fed DPW as a feedstuff is shown in Table 41. Some of these results are expressed as a percent change from the control and are shown in Table 42.

The effects of replacing the soybean meal in the control ration with 5% DPW was studied by Long et al. (1969). Feed consumption per day and total feed consumed decreased slightly for the DPW fed steers, while feed per unit gain increased. Similarly, final body weight, total weight gain and average daily gain also decreased for the DPW fed steers. These results suggest that the 5% DPW was merely a diluent in the ration, as reflected in the approximately 6% decreased weight gains and efficiency of the DPW fed steers.

Reducing or eliminating shelled corn and soybean meal content in the control ration and replacing them with 10.5 or 32% DPW was studied by Bucholtz et al. (1971). Feed consumption per day and total feed consumed increased slightly and feed per unit gain greatly increased for the 10.5% DPW fed steers. Similar feed consumption trends were noted for the 32% DPW fed steers, except that the increases were amplified. Body weight gains and average daily gains were decreased for both levels of DPW. The decrease, however, was greatest for the 32% DPW fed steers. Bucholtz et al. (1971) attributed the poor performance of the DPW fed steers to the low crude protein content of the DPW utilized (Table G-7), and stated that DPW must contain more than 25% crude protein to compete with supplemental nitrogen sources for ruminants. However, all rations had comparable crude and digestible protein contents (Table G-6), and the poor performance of the DPW fed steers (Table 42) might be attributed to a combination of protein,

TABLE 41. PERFORMANCE OF FINISHING STEERS FED DPW AS A FEEDSTUFF (kilograms)

Source	Initial Body Weight	Final Body Weight	Total Weight Gain	Average Daily Gain	Feed Consumption Per Day	Feed Consumption Per kg gain	Total Feed Consumed	Total DPW Consumed
Long et al.(1969)								
Control	301.4	470.5	169.1	1.22	12.530	10.27	1741.7	-
5% DPW	307.3	466.8	159.5	1.15	12.450	10.83	1730.6	84.6
Bucholtz et al. (1971)								
Control	313.4	517.1	203.7	1.52	10.573	6.96	1416.7	-
10.5% DPW	314.8	439.9	175.1	1.31	10.632	8.14	1424.7	149.6
32% DPW	312.5	479.9	167.4	1.25	13.014	10.43	1743.9	558.0
Oliphant (1974)								
Control	163.0	428.7	265.7	1.29	7.100	5.50	1462.6	-
15% DPW	163.0	422.6	259.6	1.26	7.100	5.64	1462.6	219.4
Control	167.0	417.2	250.2	1.18	6.600	5.59	1399.2	-
14.8% DPW & Urea	163.0	415.3	252.3	1.19	6.400	5.38	1356.8	200.8
Cullison et al. (1976)								
Control	241.4	403.6	162.2	1.13	7.920	7.07	1093.0	-
13% DPW	241.9	373.9	132.0	0.90	8.490	9.33	1290.5	167.8
Oltjen and Dinius (1976)								
Control	238.0	292.0	54.0	0.60	8.508	14.18	765.9	-
15% DPW-A	259.0	350.8	91.8	1.02	9.384	9.20	844.6	126.7
15% DPW-B	248.0	325.4	77.4	0.86	8.875	10.32	799.2	119.9

TABLE 42. PERFORMANCE OF FINISHING STEERS FED DPW AS A FEEDSTUFF (percent change from the control)

Source	Initial Body Weight	Final Body Weight	Weight Gain and Average Daily Gain	Feed Per Day and Total Feed Consumed	Feed Consumed per kilogram of gain
Long *et al*. (1969)					
5% DPW	+ 2.0	- 0.8	- 5.7	- 0.6	+ 5.5
Bucholtz *et al*. (1971)					
10.5% DPW	+ 0.4	- 5.3	-14.0	+ 0.6	+17.0
32% DPW	- 0.3	- 7.2	-17.8	+23.1	+49.9
Oliphant (1974)					
15% DPW	0	- 1.4	- 2.3	0	+ 2.4
14.8% DPW & Urea	- 2.4	- 0.5	+ 0.8	- 3.0	- 3.8
Cullison *et al*. (1976)					
13% DPW	+ 0.2	- 7.4	-18.6	+ 7.2	+32.0
Oltjen and Dinius (1976)					
15% DPW-A	+ 8.8	+20.1	+70.0	+10.3	-35.1
15% DPW-B	+ 4.2	+11.4	+43.3	+ 4.3	-27.2

ash and metabolizable energy or other dietary imbalances. It is clear that rations must be balanced both for protein and energy if similar animal performance is expected.

Oliphant (1974) studied the effects of replacing the soybean meal and fish meal in the concentrate portion of the control rations and incorporated 15% DPW or 14.8% DPW plus urea (percent of total diet) in two experimental feeding trials. Feed consumption per day and total feed consumed for the 15% DPW fed steers was similar to the control steers, but feed per unit gain increased slightly for the DPW fed steers. Conversely, the 14.8% DPW plus urea fed steers decreased feed consumption per day, total feed consumed and feed per unit gain. Final body weight, total weight gain and average daily gain was slightly reduced for the 15% DPW fed steers. The weight parameters for the 14.8% DPW plus urea fed steers were similar to controls. It is difficult to interpret the performance of the DPW fed steers because the ration characteristics, with the exception of crude protein, were not reported and the studies were not conducted simultaneously. It can only be concluded that the 15% DPW fed steers performed slightly poorer than the control steers, while the 14.8% DPW plus urea fed steers performed slightly better than the controls.

The effects of eliminating soybean meal, reducing the peanut hull and molasses content of the control ration and replacing them with 13% DPW was studied by Cullison *et al*. (1976). Performance of the DPW fed steers was adversely affected; feed consumption increased and weight parameters were greatly reduced. The authors attributed the inefficient performance of the DPW fed steers to something present in the hen manure, either as a result of natural phenomena or as the result of the drying process.

Oltjen and Dinius (1976) studied the effects of eliminating the peanut hulls and urea, reducing the corn content in the control ration and replacing them with 15% DPW. The only difference between the DPW rations A and B are their nutrient characteristics (Table G-6). Both groups of DPW fed steers outperformed the control group. These results, however, were confounded by two factors: (1) the poor performance of the control steers; and (2) the pretrial diet fed the DPW steers. The authors concluded that the control steers poorly utilized the urea in their ration, ruminal fill was lowered and the peanut hulls had a depressing influence on weight gains. Therefore, any comparisons to the control group would be invalid and would bias any observed increased performance of the DPW fed steers. Prior to the study, the DPW fed steers were on a maintenance diet, and the authors believed that compensatory growth occurred during the first half of the trial, as evidenced by 40% greater gains during that period.

The evaluation of utilizing DPW as a feedstuff in growing and finishing steer rations has revealed several trends. However, because of the extreme variation in performance of the DPW steers and of control animals, significant correlations were not obtained. Nevertheless, the results suggested that the maximum animal response level of incorporating DPW into steer rations may be 5%, on the basis of feed consumption per kilogram of gain (Figure 24).

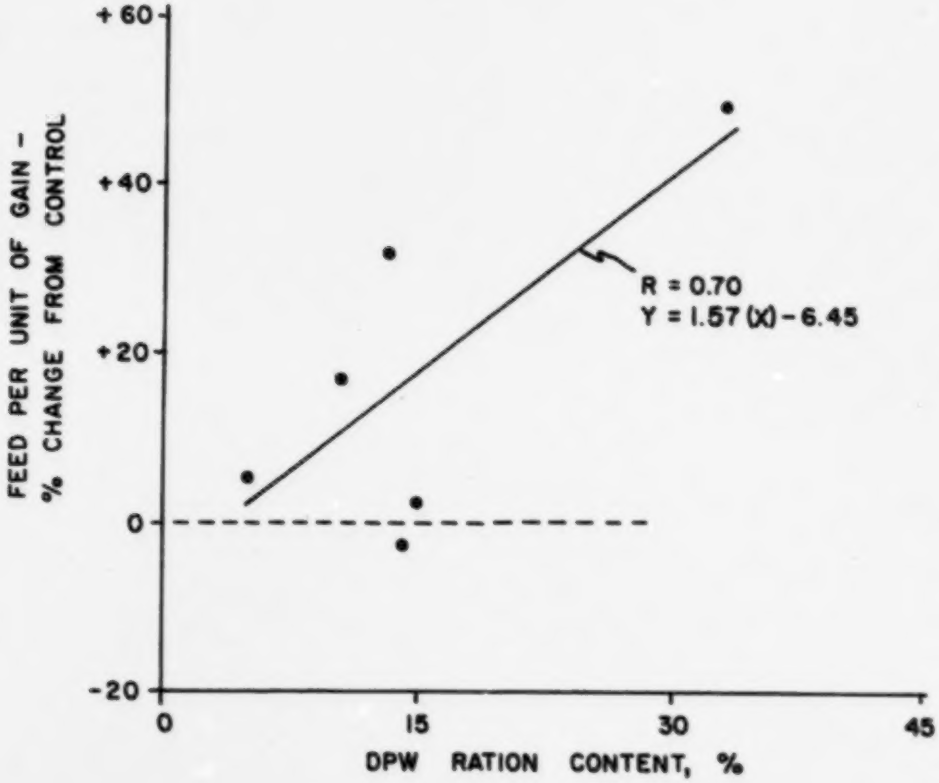

Figure 24. Relationship Between DPW Ration Content and Feed Consumption Per Unit of Body Weight Gain for Steers Fed DPW

Economic Value Estimation

The economic estimation of the value of DPW as a feedstuff for finishing steers (based on feed costs, animal costs and selling prices, and economic return) are shown in Table 43. Some of these economic results are expressed as a percent change from the control in Table 44.

The incorporation of 5% DPW into a steer ration (Long et al., 1969) reduced feed costs (per tonne, per day and total feed). The magnitude was less for feed costs per kilogram of gain and is attributed to the lower body weight gains of the DPW steers. The slightly increased economic return for the DPW group reflects only feed cost savings, because animal growth was depressed and therefore selling prices were lower. Although the calculated gross value of DPW was positive ($33.73 per tonne), when drying and other costs are considered, the value will be lower.

Steer rations containing 10.5% and 32% DPW (Bucholtz et al., 1971), reduced feed costs (per tonne, per day and total feed). Feed costs per kilogram of gain were slightly increased for the 10.5% DPW group because of lower weight gains not completely offset by the reduced feed costs. Conversely, the 32% DPW group feed costs per kilogram of gain were reduced, because the greatly reduced feed costs offset the lowered weight gains. The economic return for both DPW groups was lower than the control group, which is attributed to the lower weight gains of the DPW steers. Although feed costs were reduced for the DPW groups, they were unable to offset the reduced economic returns, and therefore the gross value of DPW per tonne was negative.

All feed costs for steer rations containing 15% DPW or 14.8% plus urea (Oliphant, 1974) were reduced. Although body weight gains were slightly lower for the 15% DPW group, feed cost savings offset them, and the economic return was increased. Conversely, the body weight gains of the 14.8% DPW plus urea group were slightly increased and therefore the increased economic return reflects both feed cost savings and improved animal performance of this group. Because of the increased economic returns for both DPW groups, the gross value of DPW per tonne is positive.

The incorporation of 14% DPW into steer rations (Cullison et al., 1976) decreased some feed costs (per tonne, per day and total feed). However, feed costs per kilogram of gain increased because of reduced body weight gains by the DPW fed steers. Similarly, the reduced body weight gains caused the animal selling prices to decrease and this, in turn, greatly reduced the economic return. The reduced economic return, which was not offset by feed cost savings, caused the gross value of DPW per tonne to be negative.

Incorporating 15% DPW from two sources into growing steer rations decreased all feed costs (per tonne, per day, total feed and per kilogram of gain)(Oltjen and Dinius, 1976). Due to the inefficient performance of the control group, any economic comparisons to the DPW groups are highly biased.

The economic assessment of the practice of utilizing DPW as a feedstuff

TABLE 43. ECONOMIC ESTIMATE OF THE VALUE OF DPW AS A FEEDSTUFF FOR FINISHING STEERS (dollars)

Source	Feed Cost Per Tonne	Feed Cost Per Day	Feed Cost Per Kg Gain	Total Feed Cost	Animal Cost	Animal Selling Price	Economic Return	Gross Value per Tonne of DPW
Long *et al*. (1969)								
Control	103.00	1.2906	1.0578	179.39	465.12	726.08	81.57	-
5% DPW	93.60	1.1653	1.0137	161.97	474.24	720.38	84.17	30.73
Bucholtz *et al*. (1971)								
Control	94.10	0.9949	0.6549	133.32	483.64	797.99	181.03	-
10.5% DPW	81.00	0.8612	0.6593	115.40	485.80	756.01	154.81	-175.27
32% DPW	54.30	0.7067	0.5663	94.70	482.25	740.58	163.63	- 31.18
Oliphant (1974)								
Control	119.70	0.8499	0.6588	175.08	251.54	661.57	234.95	-
15% DPW	89.80	0.6376	0.5060	131.35	251.54	652.16	269.27	156.43
Control	119.70	0.7900	0.6695	167.48	257.71	643.82	218.62	-
14.8% DPW & Urea	89.60	0.5734	0.4819	121.56	251.54	640.89	267.79	244.87
Cullison *et al*. (1976)								
Control	103.90	0.8229	0.7346	113.56	372.53	622.84	136.75	-
13% DPW	85.80	0.7284	0.8005	110.72	373.30	577.00	92.98	-262.22
Oltjen and Dinius (1976)								
Control	80.10	0.6817	1.1358	61.35	367.28	450.61	21.98	-
15% DPW-A	67.50	0.6334	0.6210	57.01	399.69	541.35	84.66	494.71
15% DPW-B	67.50	0.5994	0.6966	53.95	382.71	502.16	65.50	362.97

TABLE 44. ECONOMIC ESTIMATE OF THE VALUE OF DPW AS A FEEDSTUFF FOR FINISHING STEERS (percent change from the control)

Source	Feed Cost Per Tonne	Feed Cost Per Day and Total Feed Cost	Feed Cost Per Kg Gain	Animal Cost	Animal Selling Price	Economic Return
Long et al. (1969)						
5% DPW	- 9.1	- 9.7	- 4.2	+ 2.0	- 0.8	+ 3.2
Bucholtz et al. (1971)						
10.5% DPW	-13.9	-13.4	+ 0.8	+ 0.4	- 5.3	-14.5
32% DPW	-42.3	-29.0	-13.5	- 0.3	- 7.2	- 9.6
Oliphant (1974)						
15% DPW	-25.0	-25.0	-23.2	0	+ 1.4	+14.6
14.8% DPW & Urea	-25.1	-27.4	-28.0	- 2.4	- 0.5	+22.5
Cullison et al. (1976)						
13% DPW	-17.4	-11.5	+ 9.0	+ 0.2	- 7.4	-32.0
Oltjen and Dinius (1976)						
15% DPW-A	-15.7	- 7.1	-45.3	+ 8.8	+20.1	+285.2
15% DPW-B	-15.7	-12.1	-38.7	+ 4.2	+11.4	+198.0

in growing and finishing steer rations did not delineate any maximum economic level for its incorporation into a ration. This may be attributed to the extreme variation in performance of DPW fed steers and the lack of repeatability between studies. Maximum or "optimum" economic levels of incorporating DPW into steer rations cannot be determined at this time and must await results from future feeding trials that are independently confirmed.

In summary, the utilization of DPW as a feedstuff for finishing steers decreased animal performance, as reflected by increased feed consumption and decreased weight gains, when compared to control animals. Although the economic returns were generally decreased for the DPW fed steers, they were offset in some studies by feed cost per tonne savings, which resulted in a positive gross value. The animal performance evaluation and the economic assessment of the practice of utilizing DPW as a feedstuff for finishing steers failed to clearly delineate its value, due to the lack of repeatability between studies and abnormal animal performance by control steers. The delineation of the possible benefits must await future feeding trials that are independently confirmed.

DPW FED TO DAIRY COWS

The utilization of DPW as a feedstuff in dairy cow rations has been investigated in 11 studies. Only four studies met the selection criteria and were evaluated (Table G-9).

The composition of the rations utilized in the evaluated studies is shown in Table G-10. Crude protein levels were reported in the original studies by Thomas *et al*. (1972), Silva *et al*. (1976) and Smith *et al*. (1976), and all other characteristics were calculated. The incorporation of DPW into dairy cow rations generally increased ash, calcium, phosphorus, and decreased TDN and metabolizable energy levels.

The study by Thomas *et al*. (1972) incorporated 30.2% DPW into the concentrate portion of the ration. However, when considering the hay, corn silage and concentrate consumption, DPW composed 4.7% of the total ration and was evaluated at that level.

Similarly, Kneale and Garstang (1975) incorporated 10 and 20% DPW into the concentrate portion of the ration in the first of two studies. Considering the total daily consumption of hay and concentrate, DPW composed 8.5 and 17% of the total ration, and was evaluated at those levels. In the second study, DPW was incorporated at 20% into the concentrate portion of the ration. Considering the total daily consumption of hay and concentrate, DPW composed 10.9% of the total ration and was evaluated at that level.

Smith *et al*. (1976) also incorporated 30.2% DPW into the concentrate portion of the ration. When considering the hay, corn silage and concentrate consumption, DPW composed 15.9% of the total ration and was evaluated at that level.

The study by Silva *et al*. (1976) was a direct substitution of 10, 20, or

30% DPW for citrus pulp and was evaluated at those levels.

The composition of the DPW utilized in the studies by Kneale and Garstang (1975) and Silva et al. (1976) is shown in Table G-11. Sources of manure and dehydration methods of the DPW utilized in the feeding trials are shown in Table G-12.

Animal Performance Evaluation

The performance of dairy cows (feed consumption, feed conversion and milk production) fed DPW as a feedstuff is shown in Tables 45 and 46.

The effects of feeding 4.7% DPW to lactating dairy cows were studied by Thomas et al. (1972). In comparison to the control group, feed consumption per day and total feed consumed increased, feed efficiency decreased, and milk production increased for the DPW group. Milk fat percentages were higher for the DPW group than the control group (3.87 versus 3.30%).

In the first of two studies, Kneale and Garstang (1975) studied the effects of feeding 8.5 and 17% DPW to lactating cows. Feed consumption per day for the DPW cows was restricted to that of the control cows. In comparison to the control group, the feed conversion ratio improved and milk production increased for the 8.5% DPW group, whereas the opposite performance was observed for the 17% DPW group. In the second study, the effects of feeding 10.9% DPW to dairy cows were studied. Feed consumption per day for the DPW cows again was restricted to that of the control cows. The feed conversion ration and milk production for the DPW group was the same as the control group.

Silva et al. (1976) investigated the effects of substituting 10, 20, or 30% DPW for citrus pulp in dairy cow rations. Feed consumption per day and total feed consumed for the 10% DPW group was comparable to controls, although the feed conversion ratio for the DPW group was poorer and milk production was slightly decreased. All parameters for the 20 and 30% DPW groups were lower than the control group. Milk fat percentages for the control, 10, 20 and 30% DPW groups were 3.41%, 3.19%, 3.45% and 3.36% respectively, and were not influenced by DPW content.

Smith et al. (1976) studied the effects of feeding 15.9% DPW to lactating cows. Feed consumption per day and total feed consumed decreased, the feed conversion ration improved, and milk production decreased for the DPW fed cows. The milk fat percentages for the control and DPW groups were comparable (3.7% and 3.6%, respectively), as were the birth weight of calves (45 and 46 kg, respectively).

The animal performance evaluation of the practice of utilizing DPW as a feedstuff in dairy cow rations revealed correlations between DPW and the animal response parameters. Feed consumption per day and milk production (expressed as a percent change from the control) were inversely correlated to DPW content (Figure 25). Utilizing the data in Figure 25, the maximum animal response level of incorporating DPW into dairy cow rations is approximately 10-12% or less.

TABLE 45. PERFORMANCE OF DAIRY COWS FED DPW AS A FEEDSTUFF (kilograms)

Source	Ration	Feed Consumption Per Day	Feed Consumption Per Kg. Milk	Total Feed Consumed	Total DPW Consumed	Milk Production Per Day	Total Milk Production
Thomas et al. (1972)	Control	38.3	1.982	3255.5	-	19.3	1640.5
	4.7% DPW	46.6	2.262	3961.0	186.2	20.6	1751
Kneale and Garstang (1975)	Control	11.235	0.864	1887.5	-	13.0	2184
	8.5% DPW	11.235	0.824	1887.5	160.4	13.63	2289.8
	17% DPW	11.235	0.878	1887.5	320.9	12.79	2148.7
	Control	11.235	0.735	786.5	-	15.29	1070.3
	10.9% DPW	11.235	0.735	786.5	85.7	15.29	1070.3
Silva et al. (1976)	Control	25.3	1.193	2125.2	-	21.2	1780.8
	10% DPW	25.4	1.233	2133.6	213.4	20.6	1730.4
	20% DPW	20.3	1.187	1705.2	341.0	17.1	1436.4
	30% DPW	15.4	1.108	1293.6	388.1	13.9	1167.6
Smith et al. (1976)	Control	14.1	0.825	1269	-	17.1	1539
	15.9% DPW	12.5	0.812	1125	178.9	15.4	1386

Table 46. PERFORMANCE OF DAIRY COWS FED DPW AS A FEEDSTUFF (percent change from the control)

Source	Feed Consumption Per Day & Total Feed	Feed Consumption Per Kg. Milk	Milk Production Per Day and Total
Thomas _et_ _al_. (1972)			
4.7% DPW	+21.7	+14.1	+ 6.7
Kneale and Garstang (1975)			
8.5% DPW	-	- 4.6	+ 4.8
17% DPW	-	+ 1.6	- 1.6
10.9% DPW	-	0	0
Silva _et_ _al_. (1976)			
10% DPW	+ 0.4	+ 3.4	- 2.8
20% DPW	-19.8	- 0.5	-19.3
30% DPW	-39.1	- 7.1	-34.4
Smith _et_ _al_. (1976)			
15.9% DPW	-11.3	- 1.6	- 9.9

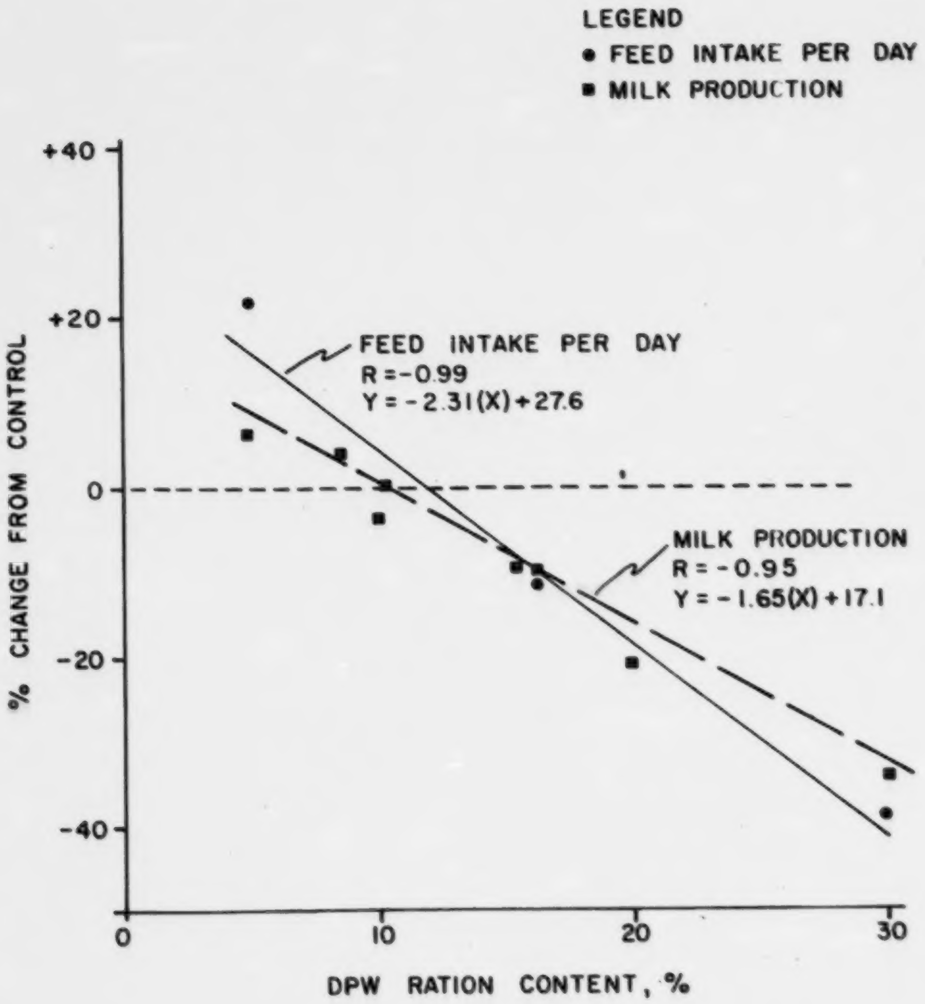

Figure 25. Relationships Between DPW Ration Content, Feed Consumption Per Day, and Milk Production for Dairy Cows Fed DPW

Economic Value Estimation

The economic evaluation of the value of DPW as a feedstuff for dairy cows (based on feed costs, milk revenue, and economic returns) is shown in Tables 47 and 48.

In the study by Thomas et al. (1972), utilizing DPW as a feedstuff decreased all feed costs for the DPW group. In contrast to the control group, the milk revenue was increased for the DPW group due to their increased milk production. The economic return for the DPW group was larger than the controls and reflected both feed cost savings and increased milk revenue. The high gross value of DPW is a reflection of the increased economic return of that group.

In the first study by Kneale and Garstang (1975), all feed costs were reduced for both DPW groups, with the magnitude being largest for the 17% DPW ration. In contrast to the control group, milk revenues were increased for the 8.5% DPW group, but decreased for the 17% DPW group. The economic returns for both DPW groups were larger than for the control group. The economic return for the 8.5% DPW group reflects both feed cost savings and increased milk revenue, whereas the economic return for the 17% DPW group reflects only feed cost savings. The calculated gross value of the DPW for the 8.5% group is larger than the 17% group. The 17% DPW group consumed twice as much DPW to maintain a comparable economic return as did the 8.5% DPW group. In the second study, all feed costs were lower for the DPW group than for the control group, and milk revenues were similar. The economic return for the 10.9% DPW group was slightly increased and reflects only feed cost savings. The calculated gross value of DPW is lower than those in the first study, due to the lower cost of the control ration and the absence of improved milk production.

The substitution of 10, 20, and 30% DPW for citrus pulp (Silva et al., 1976) reduced all feed costs and also reduced milk revenues, in a direct relationship with DPW content. The economic returns reflect only feed cost savings and were diminished by lowered milk revenues as the DPW content increased. The calculated gross values of DPW decreased in a direct relationship with DPW content. This decrease may be attributed to the decreases in milk revenues that were not offset by decreasing feed costs.

In the study by Smith et al. (1976), the utilization of DPW as a feedstuff decreased all feed costs. Milk revenues, however, also were decreased. The economic return for the DPW group was slightly increased and reflects only feed cost savings that were diminished by lowered milk revenues. The low calculated gross value of the DPW is attributed to poor animal performance that was not offset by feed cost savings.

The economic assessment of the practice of utilizing DPW as a feedstuff in dairy cow rations revealed correlations between economic parameters and DPW ration content. Milk revenues (when expressed as a percent change from the control) were highly correlated (R= -0.95) with DPW ration content (Figure 26). Similarly, the economic return also correlated with DPW ration content (Figure 26). When DPW is utilized at 10% or less, milk revenues

TABLE 47. ECONOMIC ESTIMATE OF THE VALUE OF DPW AS A FEEDSTUFF FOR DAIRY COWS (DOLLARS)

Source	Feed Cost Per Tonne	Feed Cost Per Day	Feed Cost Per kg Milk	Total Feed Cost	Milk Revenue Per Day	Total Milk Revenue	Economic Return	Gross Value Per Tonne of DPW
Thomas *et al.* (1972)								
Control	49.70	1.9035	0.0986	161.80	4.68	397.80	236.00	-
4.7% DPW	31.60	1.4726	0.0715	125.17	5.00	425.00	299.83	342.80
Kneale & Garstang (1975)								
Control	120.50	1.3538	0.1041	227.44	3.15	529.62	302.18	-
8.5% DPW	104.80	1.1774	0.0864	197.80	3.30	555.28	357.48	344.76
17% DPW	87.00	0.9774	0.0764	164.20	3.10	521.06	356.86	170.40
Control	104.90	1.1786	0.0771	82.50	3.71	259.55	177.05	-
10.9% DPW	90.30	1.0145	0.0664	71.01	3.71	259.55	188.54	134.07
Silva *et al.* (1976)								
Control	114.40	2.8943	0.1365	243.12	5.14	431.84	188.72	-
10% DPW	100.50	2.5527	0.1239	214.43	5.00	419.62	205.19	77.18
20% DPW	89.30	1.8128	0.1060	152.28	4.15	348.33	196.05	21.50
30% DPW	78.10	1.2027	0.0865	101.03	3.37	283.14	182.11	-17.03
Smith *et al.* (1976)								
Control	86.40	1.2182	0.0712	109.64	4.14	373.21	263.57	-
15.9% DPW	53.00	0.6625	0.0430	59.62	3.73	336.10	276.48	72.16

TABLE 48. ECONOMIC ESTIMATE OF THE VALUE OF DPW AS A FEEDSTUFF FOR DAIRY COWS (percent change from the control)

Source	Feed cost per tonne	Feed cost per day and total feed cost	Feed cost per kg milk	Milk revenue per day and total milk revenue	Economic return
Thomas *et al.* (1971)					
4.7% DPW	-36.4	-22.6	-27.5	+ 6.8	+27.0
Kneale & Garstang (1975)					
8.5% DPW	-13.0	-13.0	-17.0	+ 4.8	+18.3
17% DPW	-27.8	-27.8	-26.6	- 1.6	+18.1
10.9% DPW	-13.9	-13.9	-13.9	0	+ 6.5
Silva *et al.* (1976)					
10% DPW	-12.1	-11.8	- 9.2	- 2.8	+ 8.7
20% DPW	-21.9	-37.4	-22.3	-19.3	+ 3.9
30% DPW	-31.7	-58.4	-36.6	-34.4	- 3.5
Smith *et al.* (1976)					
15.9% DPW	-38.7	-45.6	-39.6	- 9.9	+ 4.9

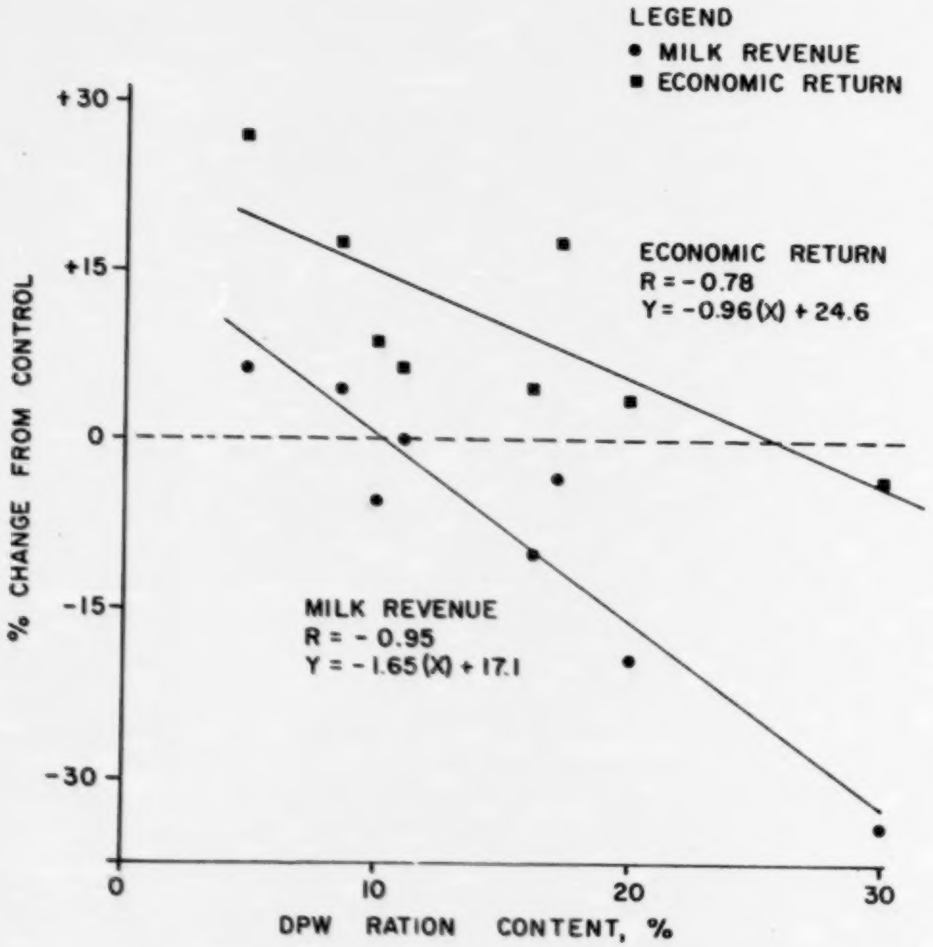

Figure 26. Relationships Between DPW Ration Content, Milk Revenue, and Economic Return For Dairy Cows Fed DPW

appear to be similar or improved when compared to those from control animals. However, DPW can be utilized at 25% or less and the economic return will be similar or improved when compared to control cows.

Discussion

The animal performance evaluation and the economic assessment of the study by Thomas et al. (1972) suggest incentives exist for feeding 4.7% DPW to dairy cows. However, close scrutiny of the feed consumption data indicates that the DPW group increased feed consumption by 22% per day. This increased consumption was not the concentrate portion of the ration (which contained the DPW), but was an increase in corn silage intake. This drastic increase in corn silage consumption confounds the evaluation of the study, and the benefits observed may have been caused by the increased corn silage consumption and not the DPW.

The drastic increase in feed consumption by DPW fed cows in the above study was circumvented by Kneale and Garstang (1975), who restricted feed consumption of the DPW fed cows to that of the control cows and evaluated the influence of various levels of DPW on feed conversion ratios and milk production. The results indicate that incorporating 8.5% DPW into a dairy cow ration resulted in improved performance and indicates that a large economic incentive may exist for its utilization at this level. The results also indicate that feeding rations containing 10.9 or 17% DPW result in no improved animal performance and the economic incentive is reduced. The authors attributed the poor performance of cows fed these rations to an energy-related problem in the rations, but because no ration characteristics were reported in these studies, this attribution could not be evaluated. Based upon the results of these studies, the maximum level of incorporating DPW into dairy cow rations is about 11%. At this level milk production is not diminished (Figure 25), and although economic incentives exist for the utilization of DPW at higher levels (Table 47), milk production decreases and causes fixed costs to increase, which results in reduced or negligible economic incentives.

The negative results of the study by Silva et al. (1976) can be attributed to a palatability problem. The authors noted that the higher ash content and degree of fineness of the DPW had a marked effect on ration density and caused the 20 and 30% DPW rations to be unpalatable. The ash content of the DPW utilized in this study was 60.3% (Table G-11). Utilizing this material as a feedstuff would be comparable to feeding "ground rocks" as described by Whetstone et al. (1974). The results of this study dramatically indicate the problem encountered when DPW is treated with excessive heat; organic matter is destroyed and the resultant product has a very low nutritive value.

The negative results of the study by Smith et al. (1976) also can be attributed to a palatability problem. The authors suggest that when the concentrate containing DPW came into contact with the corn silage, an odor was emitted which depressed intake and adversely affected animal performance. The authors reported a calculated value of $30 per tonne (based upon 1973 prices) for the DPW utilized in their study. However, based upon 1979 prices, the calculated value of the DPW was higher ($72.16).

In summary, the evaluation of animal performance and the economic assessment of utilizing DPW as a feedstuff for lactating dairy cows indicated that benefits can be realized when low levels (10-12%) of DPW are incorporated into a ration. If the DPW content is increased above 10-12% the benefits will be diminished or negated.

DPW FED TO HEIFERS

The utilization of DPW as a feedstuff in heifer rations has been investigated in seven studies but only one study fulfilled the selection criteria. A second study was included in the evaluation because it illustrated the effects of feeding different levels of DPW and different ration compositions upon animal performance. Unfortunately this study (Keys and Smith, 1978) had no control group. The studies evaluated and the composition of the rations utilized in the studies are shown in Tables G-13 and G-14.

Animal Performance Evaluation

The performance of heifers (body weights, feed consumption and feed conversion) fed DPW as a feedstuff are shown in Tables 49 and 50. Cooper *et al*. (1974) examined the effect of replacing soybean meal with DPW. The level of DPW in the experimental ration was 21.9%. All feed consumption parameters increased significantly for the DPW fed heifers with increased feed consumption partially offset by slightly improved weight gains.

The effect of incorporating DPW into three different types of heifer rations was studied by Keys and Smith (1978). The three ration compositions were: Ration 1 - 11.1% DPW, 27.9% corn stover and 61% corn silage; Ration 2 - 11.6% DPW and 88.4% ground-corn; and Ration 3 - 25.3% DPW, 25% corn stover and 49.7% ground corn. The heifers fed Ration 2 performed most efficiently having the best feed conversion efficiency and the highest weight gains. The most inefficient level of animal performance was produced by Ration 3. The results indicate that incorporating DPW into a ground corn ration can result in efficient animal performance when compared to rations containing corn stover or corn silage. This improved performance possibly is related to the increased digestible protein and metabolizable energy levels of the DPW plus ground corn ration (Table G-14).

Economic Value Estimation

The economic estimation of the value of DPW as a feedstuff for heifers (based on feed costs, animal cost and selling prices, and economic returns) is shown in Table 51 and 52.

The substitution of DPW for soybean meal (Cooper *et al*., 1974) significantly reduced all feed costs. The slightly improved body weight gains of the DPW fed heifers resulted in decreased feed conversion costs. The increased economic return reflects both feed cost savings and improved animal performance. The calculated gross value of DPW ($222.53 per tonne) may accurately reflect its worth as a feedstuff for heifers.

TABLE 49. PERFORMANCE OF HEIFERS FED DPW AS A FEEDSTUFF (kilograms)

Source	Initial Weight	Final Weight	Weight Gain	Average Daily Gain	Feed Consumption Per Day	Feed Consumption Per Kg Gain	Total Feed Consumed	Total DPW Consumed
Cooper *et al.* (1974)								
Control	216	306.7	90.7	0.81	5.953	7.35	666.7	-
21.9% DPW	216	307.8	91.8	0.82	6.388	7.79	715.5	156.7
Keys and Smith (1978)								
11.1% DPW	398	433.7	35.7	0.51	8.00	15.686	560	62.2
11.6% DPW	398	449.1	51.1	0.73	8.20	11.233	574	66.6
25.3% DPW	398	428.8	30.8	0.44	9.40	21.364	658	166.5

TABLE 50. PERFORMANCE OF HEIFERS FED DPW AS A FEEDSTUFF (percent change from the control)

Source	Initial Weight	Final Weight	Weight Gain and Average Daily Gain	Feed Consumption Per Day and Total Feed Consumption	Feed Consumption Per Kg Gain
Cooper *et al.* (1974) 21.9% DPW	0	+ 0.4	+ 1.2	+ 7.3	+ 6.0

TABLE 51. ECONOMIC ESTIMATE OF THE VALUE OF DPW AS A FEEDSTUFF FOR HEIFERS (dollars)

Source	Feed Cost Per Tonne	Feed Cost Per Day	Feed Cost Per Kg Gain	Total Feed Cost	Animal Cost	Animal Selling Price	Economic Return	Gross Value per Tonne of DPW
Cooper *et al*. (1974)								
Control	62.00	0.3691	0.4557	41.35	357.16	507.13	108.62	-
21.9% DPW	11.60	0.0741	0.0904	8.30	357.16	508.95	143.49	222.53
Keys and Smith (1978)								
11.1% DPW	13.80	0.1104	0.2165	7.73	658.09	717.12	51.30	-
11.6% DPW	94.30	0.7733	1.0593	54.13	658.09	742.59	30.37	-
25.3% DPW	57.20	0.5377	1.2220	37.64	658.09	709.02	13.29	-

TABLE 52. ECONOMIC ESTIMATE OF THE VALUE OF DPW AS A FEEDSTUFF FOR HEIFERS (percent change from the control)

Source	Feed Cost Per Tonne	Feed Cost Per Day and Total Feed	Feed Cost Per Kg Gain	Animal Cost	Animal Selling Price	Economic Return
Cooper *et al*. (1974)						
21.9% DPW	-81.3	-79.9	-80.2	0	+ 0.4	+32.1

The lack of a control group confounded the economic assessment of the feeding trial by Keys and Smith (1978). However, economic assessment of the three DPW rations can be performed if any calculated values of DPW are excluded. All feed cost parameters were very low for Ration 1 heifers (DPW, corn stover and silage), which may be attributed to the low costs of corn stover and corn silage. The economic return for Ration 1 heifers is the highest, which reflects the feed cost savings. Heifers fed Ration 2 (DPW and ground corn) had the best animal performance, which was reflected in their selling price. However, feed costs were the highest for Ration 2, which may be due to the high cost of ground corn. Heifers fed Ration 3 (DPW, ground corn and corn stover) had intermediate feed costs and their economic return was the lowest due to the poor animal performance.

Discussion

The review of the literature revealed few studies concerning the feeding of DPW to growing heifers; therefore, "optimum" animal response and economic levels of feeding DPW cannot be ascertained. A study by Cooper *et al*. (1974) indicating that approximately 22% DPW can be utilized as a protein supplement with corn silage in a wintering ration for heifers agrees with the work by Clanton and Jones (1975) and Essig *et al*. (1977).

The results of the study by Keys and Smith (1978) indicate that when approximately 11-25% DPW is incorporated into a ground corn based ration, animal performance is superior to those fed rations containing DPW and corn silage or DPW, corn stover and ground corn. However, because of the higher price of ground corn, when compared to corn silage or corn stover, the economic benefits for feeding DPW and ground corn to heifers are reduced. The concept of utilizing corn silage and DPW as a wintering ration for heifers is believed to be nutritionally and economically sound and should be further investigated.

SUMMARY OF DPW FEEDING TRIAL EVALUATIONS

The results of the evaluation of animal performance and the economic assessment of the utilization of DPW as a feedstuff in laying hen diets and ruminant rations are summarized in Table 53. Maximum animal response and economic levels of incorporation (that level which will neither enhance or adversely affect animal performance) of DPW into rations range from 5 to 35%. "Optimum" levels of incorporation (that level which will elicit the best animal performance) range from 5 to 12.5%.

The value of DPW is related to its ability to supplement rations with phosphorus, calcium and some amino acids. The limited "optimum" levels of incorporating DPW into rations emphasize the unrealistic values placed on DPW as primary energy sources.

The calculated gross value of DPW shown in Table 53 is variable and reflects its value at the "optimum" levels of incorporation into a ration. The actual value of DPW is lower because collection, storage, processing (drying), transportation, mixing and marketing costs must be taken into

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TABLE 53. A SUMMARY OF THE MAXIMUM AND "OPTIMUM" ANIMAL RESPONSE AND ECONOMIC LEVELS OF INCORPORATING DPW INTO LAYING HEN DIETS AND RUMINANT RATIONS

Species Fed	Maximum Animal Response Level, %	"Optimum" Animal Response Level, %	Maximum Economic Level, %	"Optimum" Economic Level, %	Estimated Gross Value, Dollars per Tonne	
					Maximum Level	"Optimum" Level
Laying Hen	14-20	10-12.5	20-35	10-12.5	48	280
Laying Hen*	8-11	5	12-16	5	16	186
Steers	5	<5	<5	†	31	†
Heifers	†	†	†	†	†	†
Dairy Cows	10-12	<11-12	10-25	5-10	166	225

* Diets supplemented with lard or soybean oil

† Cannot be determined from existing data

consideration. Due to the escalating energy costs, the cost of drying (Appendix F) poultry waste may exceed its value as a feedstuff. If this occurs, there must be a substantial environmental incentive to utilize machine drying as a poultry waste management alternative in order to make the continued use of DPW as a feedstuff attractive.

SECTION 8

NUTRITIVE AND ECONOMIC VALUE OF BROILER LITTER ON THE BASIS OF FEEDING TRIALS

INTRODUCTION

This section attempts to identify the value of broiler litter as a feedstuff based upon information from reported feeding trials. A total of 27 studies were identified that involved the direct utilization of broiler litter as a feedstuff for cattle. Sixteen of these studies fulfilled the evaluation criteria stated in Section 7 and were evaluated in this Section. The methodology described in Section 7 was used to evaluate the nutritional information and to identify the economic costs and benefits. The only deviation in methodology was the estimation of the gross value of composted broiler litter. The gross value of composted broiler litter was calculated on a basis of feed cost savings because no product other than weight gain was produced (i.e., no milk or calves).

The calculation was: Total kilograms of litter consumed by the litter fed animals divided by the difference in feed costs between control and litter fed animals. It was assumed that the litter was available at no cost.

AS COLLECTED BROILER LITTER FED TO STEERS

The utilization of as collected broiler litter (litter that has not been subjected to any chemical, mechanical or biological treatment), as a feedstuff for growing and finishing steers has been investigated in six studies. Four met the selection criteria and were evaluated (Table G-15).

The composition of the rations utilized in various studies is shown in Table G-16. The composition of the broiler litter reported in the various studies is shown in Table G-17. Generally, the incorporation of broiler litter into the rations increased ash, calcium, phosphorus, and decreased TDN and metabolizable energy levels.

Animal Performance Evaluation

The performance of steers (body weights, feed consumption per day, per kilogram of gain and total feed consumed) fed as collected broiler litter as a feedstuff are shown in Tables 54 and 55.

Noland et al. (1955) studied the effect of substituting broiler litter for cottonseed meal and a portion of the molasses and corn in the control

TABLE 54. PERFORMANCE OF STEERS FED AS COLLECTED BROILER LITTER AS A FEEDSTUFF (kilograms)

Source	Ration	Initial Weight	Final Weight	Weight Gain	Average Daily Gain	Feed Consumption Per Day	Feed Consumption Per Kg Gain	Total Feed Consumed	Total Litter Consumed
Noland *et al.* (1955)	Control	305.7	360.2	54.5	0.971	10.478	10.79	586.8	-
	18.72%	305.7	351.7	46.0	0.821	10.478	12.76	586.8	109.8
	Control	350.6	397.8	47.2	0.844	11.793	13.97	660.4	-
	18.75%	360.2	393.7	33.5	0.599	11.793	19.69	660.4	123.8
	Control	397.8	437.4	39.6	0.943	13.970	14.81	586.7	-
	18.77%	393.7	430.3	36.6	0.871	16.556	19.01	695.4	130.5
Southwell *et al.* (1958)	Control	313.4	449.3	135.9	0.971	10.945	11.27	1532.3	-
	9.9%	314.8	446.2	131.4	0.939	11.340	12.08	1587.6	157.2
	19.8%	317.5	447.7	130.2	0.930	11.308	12.16	1583.1	313.5
Fontenot *et al.* (1966)	Control	391	550.9	159.9	1.30	14.50	11.15	1783.5	-
	25% Hulls	379	536.4	157.4	1.28	12.90	10.08	1586.7	396.7
	25% Wood	376	523.6	147.6	1.20	12.90	10.75	1586.7	396.7
Lowrey *et al.* (1975)	Control-1	330	456.4	126.4	1.29	10.03	7.78	982.9	-
	20%	330	445.8	115.6	1.18	10.05	8.52	984.9	197.0
	Control- 2	330	443.7	113.7	1.16	9.90	8.53	970.2	-
	20%	330	445.8	115.6	1.18	10.05	8.52	984.9	197.0

TABLE 55. PERFORMANCE OF STEERS FED AS COLLECTED BROILER LITTER (percent change from the control)

Source	Ration	Initial Weight	Final Weight	Weight Gain & Average Daily Gain	Feed Consumption Per day & Total Feed	Feed Consumption Per Kg Gain
Noland et al.	18.72%	0	-2.4	-15.5	0	+18.3
(1955)	18.75%	+2.7	-1.0	-29.0	0	+40.9
	18.77%	-1.0	-1.6	- 7.6	+18.5	+28.4
Southwell et al.	9.9%	+0.4	-0.7	- 3.3	+ 3.6	+ 7.2
(1958)	19.8%	+1.3	-0.4	- 4.2	+ 3.3	+ 7.9
Fontenot et al.	25% Hulls	-3.1	-2.6	- 1.6	-11.0	- 9.6
(1966)	25% Wood	-3.8	-5.0	- 7.7	-11.0	- 3.6
Lowrey et al.	20% vs 1	0	-2.4	- 8.5	+ 0.2	+ 9.5
(1975)	20% vs 2	0	+0.5	+ 1.7	+ 1.5	- 0.1

ration. Broiler litter constituted 25% of the concentrate portion of the ration. However, when the concentrate and hay intakes are considered, broiler litter constituted 18.72%, 18.75%, and 18.77% of the total ration for trials 1, 2 and 3, respectively, and was evaluated at those levels. The first trial period lasted 56 days. The second trial was a double-reversal trial, the control steers from trial 1 were fed the litter ration and the litter fed steers from trial 1 were fed the control ration. The feed consumption of the litter-fed steers was restricted to that of the control group during trials 1 and 2. In the third trial, the litter-fed steers from trial 2 were given 15% more feed to equalize the energy intake of the litter-fed and control groups. For all trial periods the litter-fed steers gained less efficiently and at a slower rate than the control steers. When the energy intakes were equalized for both groups (trial 3), average daily gains were only slightly lower for the litter-fed steers.

Southwell et al. (1958) studied the effect of reducing or replacing cottonseed and corn in the control ration. Snapped corn was fed to the controls and the 9.9% litter groups, and ground, shelled corn was fed to the 19.8% litter group. Feed consumption per day and per kilogram of gain increased for the litter-fed steers with the increases similar for both litter-fed groups. Average daily gains were slightly lower for the litter-fed steers; however, the increases were again similar for both litter groups.

The substitution of 25% peanut hull or wood shaving broiler litter for hay and soybean meal in the control ration was studied by Fontenot et al. (1966). Feed consumption per day was reduced for both litter fed groups. The peanut-hull litter-fed steers were more efficient than either the controls or the wood-shaving litter-fed steers. Average daily gains were only slightly reduced for the peanut-hull, litter-fed steers, but they were greatly reduced for the wood-shaving litter-fed steers. These results suggest the nutritive value of peanut-hull litter may be greater than wood-shaving litter.

Lowrey et al. (1975) studied the effect of substituting 20% broiler litter for peanut hulls and reducing the soybean meal in the control ration. Control ration 2 differed from control ration 1 by having more peanut hulls and less soybean meal, and a resultant lower crude and digestible protein level (Table G-16). When the performance of the litter-fed steers was contrasted to control 1 steers, feed consumption per day increased. Feed efficiency, however, was decreased and average daily gain was reduced. Contrasting the litter group to control group 2, feed consumption per day slightly increased, feed efficiency was similar, and average daily gain was improved.

There were no significant correlations between any of the animal performance parameters and broiler litter ration content when all the studies were statistically analyzed. If the study by Noland et al. (1955) is excluded from statistical calculations, however, because feed consumption was restricted, correlations were determined. Both feed consumption per day and per kilogram of weight gain were inversely correlated with broiler litter ration content (Figure 27). These animal performance results are very limited and highly variable and only include six data points. Therefore, additional studies are required to clearly determine any animal

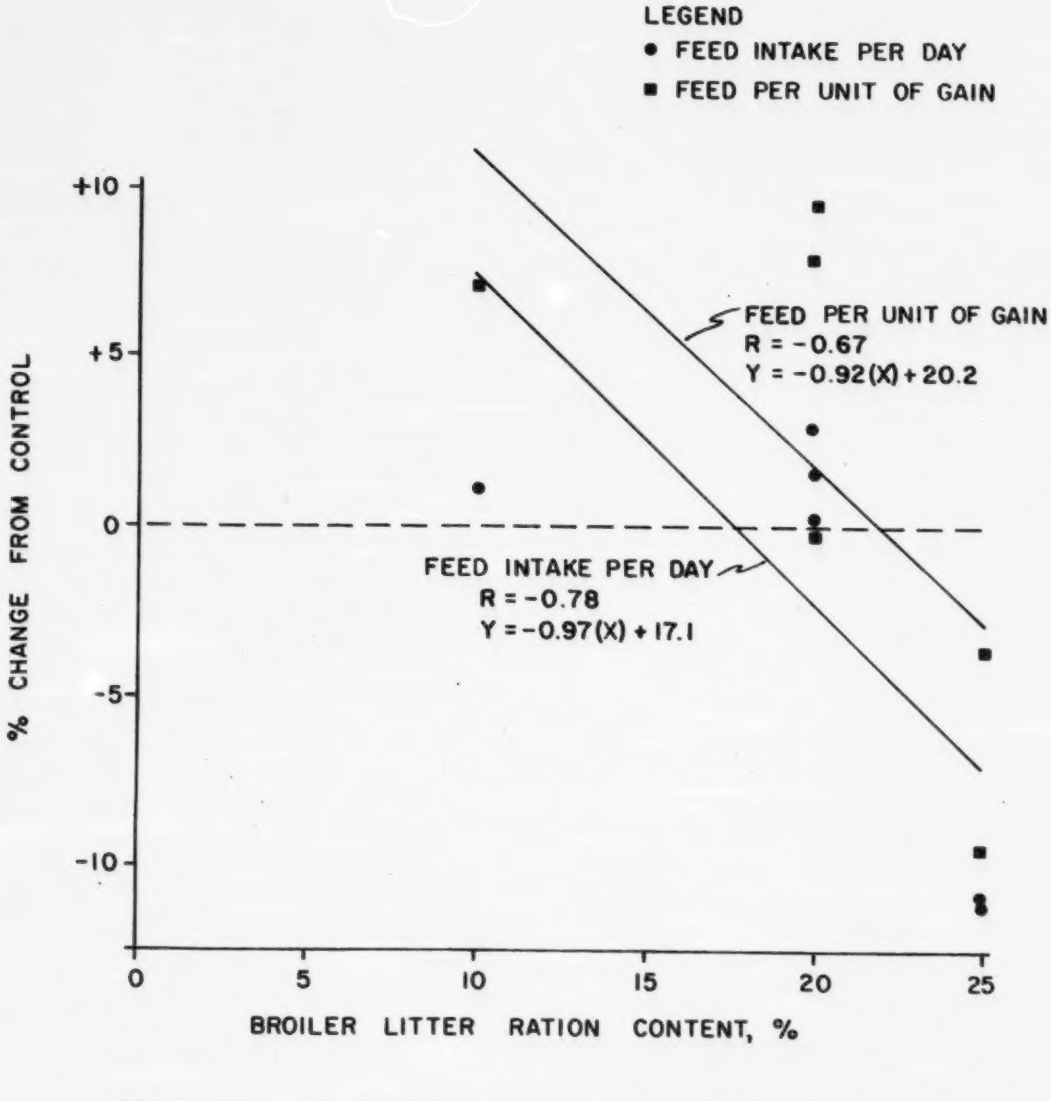

Figure 27. Relationships Between Broiler Litter Ration Content, Feed Consumption Per Day, and Feed Consumption Per Unit of Body Weight Gain For Steers Fed As Collected Broiler Litter

performance benefits from utilizing as collected broiler litter as a feedstuff for steers. The maximum animal response level of incorporating broiler litter into a steer ration that will neither improve or decrease animal performance may be approximately 18-22%. The "optimum" animal response level of incorporation may be less than 19%, but cannot be determined from the existing data.

Economic Value Estimation

The economic estimation of the value of as collected broiler litter as a feedstuff for steers (based on feed costs, animal cost and selling price, and economic return, is shown in Tables 56 and 57.

Feed costs per tonne, per day and per kilogram of gain were reduced for the broiler-litter fed steers in all three trials of the study by Noland et al. (1955). Although selling prices of the litter-fed steers were slightly decreased, this was offset by feed cost savings, and the economic return was increased for all three trials. This increased economic return reflects feed cost savings only and not improved animal performance. The poor performance of the litter-fed steers in trial 2 is reflected by the low calculated gross value of the litter ($27.30 per tonne). The gross values of broiler litter for trials 1 and 3 were similar ($78.69 and $88.97, respectively).

In the study by Southwell et al. (1958), feed costs per tonne, per day and per kilogram of gain were reduced for both groups of litter-fed steers, with the decrease being largest for the 19.8% group. Animal selling prices for the litter-fed steers were slightly lower than the controls. The economic return was increased for the litter groups. This increase, however, reflected only feed cost savings and was the largest for the 19.8% litter group. Similarly, the higher calculated gross value of litter for the 19.8% group reflected the increased feed cost savings.

Feed costs per tonne and per day were decreased for both groups of litter-fed steers in the study by Fontenot et al. (1966). Feed costs per kilogram of gain were lower for the peanut hull litter group than the wood shaving group and may be due to the improved average daily gains made by peanut-hull litter-fed steers. However, the animal selling prices were lower for both litter-fed groups when compared to the control group. The economic return was increased for both litter groups which reflects feed costs savings only. The increase was largest for the peanut hull litter group. Similarly, the calculated gross value of litter was higher for the peanut hull litter ($136.85 per tonne) than the wood shaving litter ($98.74 per tonne).

In the study by Lowrey et al. (1975), all feed costs were reduced for the broiler litter-fed steers. The decrease was largest when compared to control 1 group steers, due to their higher ration cost. The animal selling price of the litter group was reduced when compared to control 1 group steers; however, it was slightly increased when compared to control 2 group steers. The economic return of the litter group was decreased when compared to the control 1 group, reflecting the lower animal selling price that was not

TABLE 56. ECONOMIC ESTIMATE OF THE VALUE OF AS COLLECTED BROILER LITTER AS A FEEDSTUFF FOR STEERS (dollars)

Source	Ration	Feed Cost Per Tonne	Feed Cost Per Day	Feed Cost Per Kg Gain	Total Feed Cost	Animal Cost	Animal Selling Price	Economic Return	Gross Value per Tonne of Litter
Noland *et al.* (1955)	Control	101.81	1.0668	1.0987	59.74	471.76	555.86	24.36	-
	18.72%	64.74	0.6783	0.8262	37.98	471.76	542.74	33.00	78.69
	Control	101.94	1.2022	1.4244	67.32	541.05	613.88	5.51	-
	18.75%	64.82	0.7644	1.2761	42.81	555.86	607.56	8.89	27.30
	Control	104.57	1.4608	1.5491	61.35	613.88	675.00	- 0.23	-
	18.77%	64.85	1.0737	1.2327	45.10	607.56	664.06	11.38	88.97
Southwell *et al.* (1958)	Control	105.50	1.1547	1.1892	161.66	483.64	693.36	48.06	-
	9.9%	89.10	1.0104	1.0760	141.46	485.80	688.58	61.32	84.35
	19.8%	73.60	0.8323	0.8949	116.52	489.97	690.89	84.40	115.92
Fontenot *et al.* (1966)	Control	102.80	1.4906	1.1466	183.34	603.39	850.15	63.42	-
	25% Hulls	78.90	1.0178	0.7952	125.19	584.87	827.77	117.71	136.85
	25% Wood	78.90	1.0178	0.8482	125.19	580.24	808.02	102.59	98.74
Lowrey *et al.* (1975)	Control-1	102.00	1.0231	0.7931	100.26	509.26	704.32	94.80	-
	20%	89.40	0.8985	0.7614	88.05	509.26	687.96	90.65	-21.07
	Control-2	94.40	0.9346	0.8057	91.59	509.26	684.72	83.87	
	20%	89.40	0.8985	0.7614	88.05	509.26	687.96	90.65	34.32

TABLE 57. ECONOMIC ESTIMATE OF THE VALUE OF AS COLLECTED BROILER LITTER AS A FEEDSTUFF FOR STEERS (percent change from the control)

Source	Ration	Feed Cost Per Tonne	Feed Cost Per Day & Total Feed Cost	Feed Cost Per Kg Gain	Animal Cost	Animal Selling Price	Economic Return
Noland et al. (1955)	18.72%	-36.4	-36.4	-24.8	0	-2.4	+35.9
	18.75%	-36.4	-36.4	-10.4	+2.7	-1.0	+61.3
	18.77%	-38.0	-26.5	-20.4	-1.0	-1.6	N/A*
Southwell et al. (1958)	9.9%	-15.5	-12.5	- 9.5	+0.4	-0.7	+27.6
	19.8%	-30.2	-27.9	-24.7	+1.3	-0.4	+75.6
Fontenot et al. (1966)	25% Hulls	-23.2	-31.7	-30.6	-3.1	-2.6	+85.6
	25% Wood	-23.2	-31.7	-26.0	-3.8	-5.0	+61.8
Lowrey et al. (1975)	20% vs 1	-12.4	-12.2	- 4.0	0	-2.3	- 4.4
	20% vs 2	- 5.3	- 3.9	- 5.5	0	+0.5	+ 8.1

* N/A - not calculated due to negative economic return of control group

offset by feed cost savings. The economic return, however, was increased when compared to the control 2 group and reflects both feed cost savings and increased animal selling prices. The calculated gross value of litter was negative (-$21.07) when compared to the control 1 group and positive ($34.42) when compared to control 2 steers.

There were no significant correlations between any of the economic parameters and broiler litter content. Therefore, any maximum or "optimum" economic levels of incorporating broiler litter into growing, finishing steer rations cannot be determined. Based upon the maximum animal response level determined for these studies, the maximum level of incorporation may be about 20%.

Discussion

The benefits of utilizing broiler litter as a feedstuff are a factor of its nutrient composition which, in turn, are influenced by type of litter base, number of batches of birds raised on the litter, and method of handling the litter prior to its utilization as a feedstuff. In the four studies evaluated in this section, similar litter bases were not utilized. This is a major source of variation in the performance of steers fed similar levels of litter.

The nutrient composition of various types of litter is known to be highly variable (Table 58). Pine shavings have the lowest nutritive value due to its relative indigestibility. Although soybean hulls and cane bagasse have higher nutrient characteristics, their higher cost would need to be closely evaluated in any specific economic evaluation.

Utilization of broiler litter as a feedstuff in steer rations seems to be a feasible practice on the basis of nutrient value. However, the metabolizable energy of rations containing broiler litter will decrease and feed consumption per day may increase. The optimum utilization of broiler litter would appear to be in rations that are low in protein, as indicated by the study of Lowrey *et al*. (1975).

Palatability of rations containing cane bagasse litter was similar to controls (Noland *et al*. 1955). Southwell *et al*. (1958) reported a palatability problem using corn cob litter at high levels. On the basis of palatability and animal performance, the maximum animal response level incorporating broiler litter into steer rations was about 19%. However, only four studies were evaluated to determine the maximum level of incorporation and there was considerable variation between studies.

The mean economic value of as collected broiler litter determined in this section for all the evaluated studies was $71.57, which is similar to the value of $65.29 reported by Free (1977) and $77.18 reported by Fontenot (1977). These results suggest that cattle producers located near poultry producers could utilize broiler litter as a feedstuff and reduce feed costs, as long as the litter price reflects short-distance transportation, handling and storage costs.

TABLE 58. COMPOSITION AND COST OF VARIOUS TYPES OF LITTER

		---------- Percent of Dry Matter ----------				
Type	True Dry Matter Digestibility, %	Lignin	Hemicellulose	Crude Protein	TDN	Cost Per Tonne*
Peanut Hulls †	35.5	18.0_k	9.0	8.4	22.5	$ 24.91
Cane Bagasse †	46.7	14.0_k	26.7	1.1	33.7	$175.30
Corn Cobs, Ground †	60.0	4.5_s	43.7	2.0	47.9	$ 13.78
Soybean Hulls †	93.0	2.0_s	17.7	11.0	80.0	$ 88.18
Pine Wood Shavings ‡	14.5	22.4_k 15.8_s	17.4	0.7	1.5	$ 55.12

* Agway, Inc., Ithaca, New York (1979)

† Van Soest and Robertson (1976)

‡ Chandler (1980)

s-sulfuric acid method

k-permanganate method

DRIED BROILER LITTER FED TO STEERS

The utilization of dried broiler litter (DBL) as a feedstuff for growing and finishing steers has been investigated in nine studies. Four studies fulfilled selection criteria and were evaluated (Table G-18).

The composition of the rations utilized in the evaluated studies are shown in Table G-19, and the composition, sources and dehydration methods of broiler litter fed in the studies are shown in Table G-20. Generally, the incorporation of dried broiler litter into steer rations increased crude and digestible protein, ash, calcium and phosphorus, and decreased TDN and metabolizable energy levels.

Animal Performance Evaluation

The performance of steers (body weights, feed consumption per day, per kilogram of gain and total feed consumed) fed dried broiler litter as a feedstuff are shown in Tables 59 and 60.

The substitution of 25% dried broiler litter for portions of the hay, corn, alfalfa meal and soybean meal in the control steer ration did not significantly affect animal performance (Fontenot *et al.*, 1971). Feed consumption per day, efficiency and average daily gain were reduced slightly for the litter fed steers. When litter content was increased to 50%, all animal performance parameters decreased.

Substitution of 25% dried broiler litter or 25% dried broiler litter plus 10% molasses for soybean meal and portions of ear corn in the control ration significantly decreased animal performance (Webb *et al.*, 1973). Feed consumption per day, efficiency and animal body weights decreased for both groups of litter fed steers. The molasses was added to the ration in an attempt to overcome palatability problems associated with rations containing high levels of dried broiler litter, but was unsuccessful. The study by Fontenot *et al.* (1971) utilizing 25% dried litter did not significantly affect animal performance, but the same level significantly lowered animal performance in the study by Webb *et al.* (1973).

Oliphant (1974) studied the effects of substituting either 17.5%, 18.8% or 27.6% dried broiler litter for the soybean and fish meal and portions of the barley in a control steer ration. When the hay intakes are considered, dried broiler litter constituted 14.7%, 16.1%, and 23.1% of the total ration and was evaluated at those levels. All the steers receiving litter were fed for additional time periods (20 to 50 days) to allow the steers to attain similar final body weights as the control steers. Feed consumption per day decreased. However, total feed consumed increased for the litter-fed steers because of the extended trial period. Similarly, feed efficiency and average daily gain were decreased for the litter-fed steers. The author reported the slaughter weight of the 23.1% litter-fed steers to be significantly decreased, and attributed their poor performance to the lowered energy content of the ration, their reduced intake and decreased efficiency.

TABLE 59. PERFORMANCE OF STEERS FED DRIED BROILER LITTER AS A FEEDSTUFF (kilograms)

Source	Ration	Initial Weight	Final Weight	Weight Gain	Average Daily Gain	Feed Consumption Per Day	Feed Consumption Per Kg Gain	Total Feed Consumed	Total Litter Consumed
Fontenot et al. (1971)	Control	370.9	450.2	88.3	0.73	9.54	13.068	1154.3	-
	25%	377.7	458.8	81.1	0.67	9.00	13.433	1089.0	272.2
	50%	373.6	418.4	44.8	0.37	7.18	19.405	868.8	434.4
Webb et al. (1973)	Control	319.3	471.2	151.9	1.266	10.51	8.30	1261.2	-
	25%	309.4	434.1	124.7	1.039	9.59	9.23	1150.8	287.7
	25% & Molasses	312.1	435.7	123.6	1.030	9.94	9.65	1192.8	298.2
Oliphant (1974)	Control	167	405	238	1.12	6.6	5.89	1399.2	-
	14.7%	167	407	240	1.03	6.3	6.12	1474.2	216.7
	Control	163	397	234	1.23	7.1	5.77	1349.0	-
	16.1%	161	404	243	1.16	7.0	6.03	1470.0	236.7
	Control	137	398	261	1.12	6.6	5.89	1544.4	-
	23.1%	136	396	260	0.92	6.2	6.74	1760.8	406.7
Cullison et al. (1976)	Control	241.4	403.6	162.2	1.12	7.92	7.07	1148.4	-
	20% (Wood)	240.6	409.6	169.0	1.166	8.76	7.51	1270.2	254.0
	20% (Hulls)	240.3	396.9	156.6	1.08	8.61	7.97	1248.4	249.7
	Neg. Cont.	243.0	396.9	153.9	1.06	7.94	7.49	1151.3	-
	Control	219	401.2	182.2	1.20	8.74	7.28	1332.8	-
	5.8%	219.8	399.3	179.5	1.18	8.89	7.53	1355.7	78.6
	13%	219.5	388.4	168.9	1.11	8.77	7.90	1337.4	173.9

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TABLE 60. PERFORMANCE OF STEERS FED DRIED BROILER LITTER AS A FEEDSTUFF (percent change from the control)

Source	Ration	Initial Weight	Final Weight	Weight Gain & Average Daily Gain*	Feed Consumption Per Day & Total Feed Consumed*	Feed Per Kg Gain
Fontenot *et al.* (1971)	25% litter	+1.8	-0.1	- 8.2	- 5.7	+ 2.8
	50% litter	+0.7	-8.9	-49.3	-24.7	+48.5
Webb *et al.* (1973)	25% litter	-3.1	-7.9	-17.9	- 8.8	+11.2
	25% litter & Molasses	-2.3	-7.5	-18.6	- 5.4	+16.3
Oliphant (1974)	14.7% litter	0	+0.5	+ 0.8(-8.0)	- 4.5(+5.4)	+ 3.9
	16.1% litter	-1.2	+1.8	+ 3.8(-5.7)	- 1.4(+9.0)	+ 4.5
	23.1% litter	-0.7	-0.5	- 0.4(-17.9)	- 6.1(+14.0)	+14.4
Cullison *et al.* (1976)	Vs Pos. Control					
	20% Wood litter	-0.3	+1.5	+ 4.2	+10.6	+ 6.2
	20% hull litter	-0.5	-1.7	- 3.5	+ 8.7	+12.7
	Vs Neg. Control					
	20% Wood litter	-1.0	+3.2	+ 9.9	+10.3	+ 0.3
	20% Hull litter	-1.1	0	+ 1.9	+ 8.4	+ 6.4
	5.8% litter	+0.4	-0.5	- 1.6	+ 1.7	+ 3.4
	13% litter	+0.2	-3.2	- 7.4	+ 0.3	+ 8.5

* ( ) average daily gain and total feed consumption different due to different trial lengths.

In the first of two studies, Cullison et al. (1976) substituted either 20% wood shavings or 20% peanut hull-based dried litter for soybean meal, peanut hulls and minerals in two control rations. The positive control ration contained 8% soybean meal, which was omitted in the negative control ration. When compared to the positive control group, feed consumption per day increased for both litter-fed groups and feed efficiency decreased. However, the average daily weight gain of the wood shaving litter-fed steers increased, while it decreased for the peanut-hull litter-fed steers. In comparison to the negative control group, feed consumption per day increased for both litter groups. Feed efficiency of the wood-shaving litter-fed group was similar to controls and average daily gain was increased. The peanut hull litter-fed group had a decreased feed efficiency and an only slightly increased average daily gain. Because of their lower average daily gains, in comparison to the wood shaving litter group, the peanut-hull litter group was supplemented with 0.45 kilograms of peanut hulls per day from day 71 until the study terminated thus increasing average daily gains. However, although average daily gains increased after day 71, the overall average daily gain for the entire period was less than the control.

In the second study, Cullison et al. (1976) substituted 5.8% or 13% dried broiler litter for some of the corn and soybean meal in the control ration. Feed consumption per day increased, and feed efficiency and average daily gains slightly decreased for the 5.8% litter group. Feed consumption per day for the 13% litter group was similar to that of controls; however, feed efficiency and average daily gain decreased. The authors attributed the poorer performance of the 13% litter group to a lower level of total concentrate in the ration and concluded the poor performance was not related to protein source.

When all the animal response parameters were statistically analyzed, some correlations were obtained. Both feed consumption per kilogram of gain and average daily gain were correlated to dried broiler litter ration content (Figure 28). The maximum animal response level of incorporating dried broiler litter into steer rations that will neither enhance nor depress feed efficiency was 11%, and the level that will neither enhance nor depress average daily gain was 15.5%. The "optimum" animal response level of incorporating dried broiler litter into steer rations may be less than 14-18%, but cannot be determined from the available data.

Economic Value Estimation

The economic estimation of the value of dried broiler litter as a feedstuff for steers (based on feed costs, animal cost and selling price and economic return) are shown in Tables 61 and 62.

Feed costs per tonne, per day, and total feed costs decreased for both groups of litter-fed steers in a direct relationship with litter content in the study by Fontenot et al. (1971). Feed costs per kilogram of gain did not decrease in a direct relationship for the litter-fed steers due to the decreased weight gains of the 50% steers. The economic returns were tremendously increased for both litter groups and reflect both feed cost savings and the poor animal performance of the control group, due to the improved animal performance when compared to the 50% litter-fed steers.

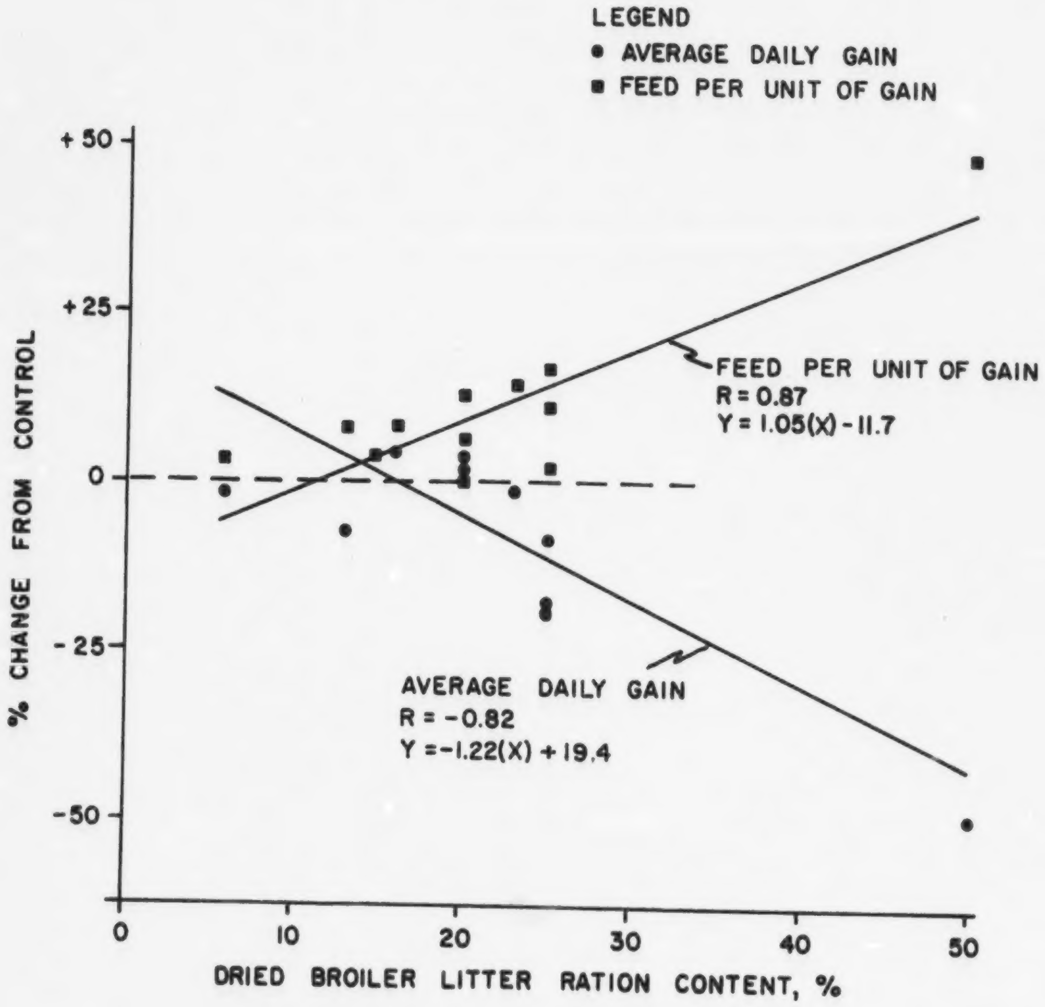

Figure 28. Relationships Between Dried Broiler Litter Ration Content, Feed Consumption Per Unit of Body Weight Gain, and Average Daily Gain for Steers Fed Dried Broiler Litter

TABLE 61. ECONOMIC ESTIMATE OF THE VALUE OF DRIED BROILER LITTER AS A FEEDSTUFF FOR STEERS (dollars)

Source	Ration	Feed Cost Per Tonne	Feed Cost Per Day	Feed Cost Per Kg Gain	Animal Cost	Total Feed Cost	Animal Selling Price	Economic Return	Gross Value Per Tonne of Litter
Fontenot *et al.* (1971)	Control	117.00	$1.1162	$1.5290	$572.37	135.06	708.63	1.20	-
	25%	87.70	0.7893	1.1781	582.87	95.51	708.02	29.64	104.48
	50%	58.50	0.4200	1.1351	576.54	50.82	654.67	27.31	60.11
Webb *et al.* (1973)	Control	86.80	0.9123	$0.7206	$492.74	109.48	727.16	124.94	-
	25%	64.30	0.6166	0.5935	477.47	73.99	669.90	118.44	-22.59
	25% & Molasses	68.00	0.6759	0.6562	481.63	81.11	672.37	109.63	-51.34
Oliphant (1974)	Control	120.70	0.7966	0.7112	257.71	168.88	625.00	198.41	-
	14.7%	90.80	0.5720	0.5553	257.71	133.85	628.08	236.52	175.87
	Control	120.70	0.8570	0.6967	251.54	162.83	612.65	198.28	-
	16.1%	89.60	0.6272	0.5407	248.46	131.71	623.45	243.28	190.11
	Control	120.70	0.7966	0.7112	211.42	186.40	614.19	216.37	-
	23.1%	80.80	0.5010	0.5446	209.88	142.28	611.11	258.95	104.70
Cullison *et al.* (1976)	Control	104.80	0.8300	0.7411	372.53	120.35	622.84	129.96	-
	20% (Wood)	85.20	0.7464	0.6401	371.29	108.23	632.11	152.59	89.09
	20% (Hulls)	85.20	0.7336	0.6793	370.83	106.37	612.50	135.30	21.39
	Neg. Control	96.10	0.7630	0.7198	375.00	110.63	612.50	126.87	-
	Control	119.60	1.0453	0.8711	337.96	159.41	619.13	121.76	-
	5.8%	110.90	0.9859	0.8355	339.20	150.35	616.20	126.65	62.21
	13%	99.80	0.8752	0.7885	338.73	133.47	599.38	127.18	31.17

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TABLE 62. ECONOMIC ESTIMATE OF THE VALUE OF DRIED BROILER LITTER AS A FEEDSTUFF FOR STEERS (percent change from the control)

Source	Ration	Feed Cost Per Tonne	Feed Cost Per Day	Feed Cost Per Kg Gain	Animal Cost	Total Feed Cost	Animal Selling Price	Economic Return
Fontenot *et al.* (1971)	25%	-25.0	-29.3	-22.9	+1.8	-29.3	-0.1	2370.0
	50%	-50.0	-62.4	-25.8	+0.7	-62.4	-7.6	2175.8
Webb *et al.* (1973)	25%	-25.9	-32.4	-17.6	-3.1	-32.4	-7.9	- 5.2
	25% & Molasses	-21.7	-25.9	- 8.9	-2.3	-25.9	-7.5	-12.3
Oliphant (1974)	14.7%	-24.8	-28.2	-21.9	0	-20.7	+0.5	+19.2
	16.1%	-25.8	-26.8	-22.4	-1.2	-19.1	+1.8	+22.7
	23.1%	-33.1	-37.1	-23.4	-0.7	-23.7	-0.5	+119.7
Cullison *et al.* (1976)	Vs Control							
	20% (Wood)	-18.7	-10.1	-13.6	-0.3	-10.1	+1.5	+17.4
	20% (Hulls)	-18.7	-11.6	- 8.3	-0.5	-11.6	-1.7	+ 4.1
	Vs Neg. Control							
	20% (Wood)	-11.3	- 2.2	-11.1	-1.0	- 2.2	+3.2	+20.3
	20% (Hulls)	-11.3	- 3.9	- 5.6	-1.1	- 3.9	0	+ 6.6
	5.8%	- 7.3	- 5.7	- 4.1	+0.4	- 5.7	-0.5	+ 4.0
	13%	-16.6	-16.3	- 9.5	+0.2	-16.3	-3.2	+ 4.5

In the study by Webb et al. (1973), all feed costs were reduced for both litter groups, but due to the cost of molasses the feed cost savings were lower for the litter plus molasses group. Because of the poor animal performance of both litter groups, animal selling prices and economic returns were negative, due to the inability of feed cost savings to offset reduced performance. Therefore, the gross values of litter for both groups were negative.

Feed costs per tonne and per day were reduced in proportion to the litter ration content in the study by Oliphant (1974). Due to the extended trial periods for the litter-fed groups, feed costs per kilogram of gain and total feed cost savings were not directly related to the litter content. Animal selling prices for the 14.7 and 16.1% litter-fed groups were increased, but slightly reduced for the 23.1% group. The economic return for all three litter fed groups was increased. The increases for the 14.7% and 16.1% groups reflect both feed cost savings and increased animal selling prices, while the increased economic return for the 23.1% group represents only feed cost savings. The estimated gross value of the litter for all three groups was positive and the mean was $156.91 ± 45.78.

All feed costs were reduced for the 20% wood-shaving and peanut hull litter-fed steers in the first study by Cullison et al. (1976). Both litter groups economically outperformed the control groups. This is reflected in the large increase in economic return and calculated gross value of dried broiler litter for the wood-shaving litter-fed group, and the slight increase for the peanut-hull litter-fed group.

In the second study by Cullison et al. (1976), all feed costs were reduced for the litter-fed steers, with the increases being largest for the 13% litter group. Animal selling prices were less for both litter fed groups and reflects their reduced weight gains. Economic returns were similarly increased for both litter-fed groups, but reflect feed cost savings only. The calculated gross value of dried broiler litter was positive for both litter-fed groups, but was highest for the 5.8% litter group.

There were no significant correlations between any of the economic parameters and dried broiler litter ration content. Maximum or "optimum" economic levels of incorporating dried broiler litter into growing and finishing steer rations could not be determined. The maximum level of incorporation may be 14-18%, based upon the maximum animal response level determined for these studies.

Discussion

The variable results delineated in the animal performance evaluation and the economic assessment of the four feeding trials did not clearly demonstrate the value of dried broiler litter as a feedstuff. The drying of the broiler litter may be a major source of variation and may alter its nutrient composition. Fontenot et al. (1971) reported that drying broiler litter at 150°C for 4 hours caused a 19% decrease in crude protein, a 59% decrease in ether extract, and a 20% increase in crude fiber.

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The results of the study by Fontenot et al. (1971) indicated that incorporating dried broiler litter into a steer ration at 50% seriously reduced animal performance. The economic incentive that appeared to exist for utilizing litter at this level is more due to the reduced performance of the control group than to the use of DBL. In contrast to the study by Fontenot et al. (1971), the study by Webb et al. (1973) indicated that due to poor animal performance, no incentives existed for the utilization of 25% dried broiler litter in steer rations, even if molasses were added. Conversely, the study by Fontenot et al. (1971) indicated that economic incentives existed for the utilization of dried broiler litter as a feedstuff for steers.

The economic assessment of the study by Oliphant (1974) revealed a possible artificial benefit for utilizing dried broiler litter as a feedstuff at 14.7 to 23.1% due to the extended trial periods. If animal performance and economic assessment are calculated for the same trial length as the controls, the economic incentive for utilizing dried broiler litter as a feedstuff for steers is greatly reduced. The average calculated gross value of litter becomes $35/tonne, instead of $157/tonne.

In the first study by Cullison et al. (1976), the evaluation revealed that wood-shaving litter was worth more as a feedstuff than peanut-hull litter. This is opposite to what the nutrient composition of the two litter bases suggests (Table 58). The digestibility of untreated wood pine shavings is 14.5% versus 35.5% for peanut hull litter (Van Soest and Robertson, 1976). Also, Fontenot et al. (1966) reported that as collected peanut hull litter utilized as a feedstuff to steers outperformed wood shaving litter. It is unclear why the wood-shaving litter-fed steers outperformed the peanut hull litter in the study by Cullison et al. (1976).

The evaluation of the feedstuff value of dried broiler litter for steers indicated that 11-16% was about the maximum animal response level of incorporation. This is in agreement with the studies of Wooden and Algeo (1976) and the second trial by Cullison et al. (1976). The calculated gross values of litter do not account for any drying costs. Due to the cost of drying broiler litter, the noted economic incentives for its utilization as a feedstuff for steers will be less.

ENSILED BROILER LITTER FED TO RUMINANTS

The utilization of ensiled broiler litter as a feedstuff for growing and finishing steers and growing heifers has been considered in seven studies. Three studies met the selection criteria and were evaluated (Table G-21). The composition of the rations used in the evaluated studies are shown in Table G-22. The composition, source and ensiling methods used in the evaluated studies are shown in Table G-23. Generally, the incorporation of ensiled broiler litter into ruminant rations increased crude and digestible protein, ash, calcium and decreased TDN and metabolizable energy levels.

Animal Performance Evaluation

The performance of ruminants (body weights, feed consumption per day, per kilogram of gain, total feed consumed, and total litter consumed) fed ensiled broiler litter as a feedstuff are shown in Tables 63 and 64.

McClure et al. (1977) combined 17% broiler litter and 83% corn silage and ensiled the mixture to yield a 30% broiler litter content (dry matter basis). When considering the grain, soybean meal, silage and litter intake as-fed, broiler litter constituted 12.8% of the total ration and was evaluated at that level. Similarly, McClure et al. (1978) added 19% broiler litter to 81% corn silage and ensiled the mixture to yield a 30% broiler litter content (dry matter basis). When considering the grain, soybean meal, silage and litter intake as-fed, broiler litter constituted 22.3% of the total ration. In both studies a negative control (corn silage plus grain) and a positive control (corn silage plus grain plus soybean meal) were utilized.

The negative control group in the 1977 study performed poorly. This may be attributed to the low crude and digestible protein content of the ration (Table G-22). When the animal performance of the 12.8% litter group was compared to the negative control group, the performance of the litter group was improved. The litter group was able to utilize the ensiled broiler litter as a supplement, and no palatability problems were encountered. When the animal performance of both litter-fed groups was compared to the positive control group, weight gains were reduced for the 12.8% litter group and increased for the 12.8% litter plus soybean meal group. Feed consumption per day increased for both litter groups and the increase was comparable to the litter content of the ration, which suggests that the litter had a diluting effect. Feed efficiency was decreased for both groups of litter-fed heifers, with the decrease being the largest for the litter without soybean meal group. The authors suggested that the concentrates required per unit of gain were similar for the positive control group and both litter groups. This comparison is of little significance because the total ration required per unit of gain increased 15.2% for the litter without soybean meal group and 7.1% for the litter plus soybean meal group.

In the 1978 study, the negative control group again performed poorly. The poor performance was attributed to the low crude and digestible protein content of the ration (Table G-22). The 22.3% litter group outperformed the negative control group in terms of weight gains. However, feed consumption per day greatly increased, and feed efficiency slightly decreased. In comparison to the positive control group, both litter groups gained more weight, but feed consumption per day greatly increased and feed efficiency decreased. The increase in feed consumption per day was similar to the litter content in the rations, suggesting that the litter might have been a diluent in the ration.

There were no significant correlations between any of the animal response parameters of heifers (expressed as a percent change from the control) and ensiled broiler ration content. However, when the comparisons to the negative control groups were deleted, several significant correlations resulted. Feed consumption per kilogram of gain increased in a direct relationship with ensiled broiler litter content. The maximum level of incorporation that will

TABLE 63. PERFORMANCE OF RUMINANTS FED ENSILED BROILER LITTER AS A FEEDSTUFF (kilograms)

Source	Initial Weight	Final Weight	Weight Gain	Average Daily Gain	Feed Consumption Per Day	Feed Consumption Per Kg Gain	Total Feed Consumed	Total Litter Consumed
Heifers								
McClure *et al.* (1977)								
Negative Control	199	306	107	0.535	8.437	15.77	1687.4	-
12.8% Control	219	402	183	0.915	14.878	16.26	2975.6	380.9
Positive Control	198	385	187	0.935	13.200	14.12	2640.0	-
12.8% litter & SBM*	215	413	198	0.990	14.969	15.12	2993.8	383.2
McClure *et al.* (1978)								
Negative Control	251.3	389.2	137.9	0.806	12.247	15.19	2094.2	-
22.3% litter	252.7	425	172.3	1.008	15.559	15.44	2660.6	593.3
Positive Control	255.8	416.4	160.6	0.939	12.564	13.38	2148.4	-
22.3% litter & SBM*	250.8	426.8	176	1.029	15.558	15.12	2660.4	593.3
Steers								
Cross *et al.* (1978)								
Control	228	372	144	0.72	8.1	11.25	1620	-
10% litter	238	418	180	0.90	8.9	9.89	1780	178
30% litter	233	421	188	0.94	9.1	9.68	1820	546
70 to 44% litter	220	388	168	0.84	5.4	6.43	1080	475.2
50% litter	223	349	126	0.63	6.7	10.63	1340	670

* Soybean meal

TABLE 64. PERFORMANCE OF RUMINANTS FED ENSILED BROILER LITTER AS A FEEDSTUFF (percent change from the control)

Source	Initial Weight	Final Weight	Weight Gain and Average Daily Gain	Feed Consumption Per Day and Total Feed Consumed	Feed Consumption Per Kilogram Gain
Heifers					
McClure *et al.* (1977)					
12.8% litter vs 1*	+10.0	+31.4	+71.0	+76.3	+ 3.1
12.8% litter vs 2†	+10.6	+ 4.4	- 2.1	+12.7	+15.2
12.8% litter & SBM‡	+ 8.6	+ 7.3	+ 5.9	+13.4	+ 7.1
McClure *et al.* (1978)					
22.3% litter vs 1*	+ 0.6	+ 9.2	+25.0	+27.0	+ 1.6
22.3% litter vs 2†	- 1.2	+ 2.1	+ 7.3	+23.8	+15.4
22.3% litter & SBM‡	- 2.0	+ 2.5	+ 9.6	+23.8	+13.0
Steers					
Cross *et al.* (1978)					
10% litter	+ 4.4	+12.4	+25.0	+ 9.9	-12.1
30% litter	+ 2.2	+13.2	+30.6	+12.3	-14.0
70 to 44% litter	- 3.5	+ 4.3	+16.7	-33.3	-42.8
50% litter	- 2.2	- 6.2	-12.5	-17.3	- 5.5

*1 Negative control group

†2 Positive control group

‡ Soybean meal

neither increase nor decrease feed consumption is 1.3% (Figure 29), indicating that ensiled broiler litter fed at any level will decrease feed efficiency and that the litter may be acting as a diluent. In terms of average daily gain, the maximum animal response level that will neither enhance nor adversely affect gains is 10%. As the litter content increased about 13.4%, average daily gain appeared to increase. These statistical analyses are for four data points only and additional studies are required to clearly determine any animal performance benefits for utilizing ensiled broiler litter as a feedstuff for heifers.

In the study by Cross et al. (1978) utilizing ensiled broiler litter as a feedstuff for growing steers, the original experimental design was modified. On day 35 of the trial the 70% broiler litter ration was changed due to extremely poor animal performance. Instead of feeding broiler litter silage at a certain percentage of the ration, the steers were allowed to consume it free choice, in addition to ground corn. For the entire period of study, this group consumed 44% broiler litter silage. This value was used in the evaluation for this group. Weight gains were increased for the 10 to 44% groups; however, they decreased for the 50% litter silage-fed steers. Feed consumption per day increased for the 10 and 30% litter groups and decreased for the 44 and 50% litter groups. Although all litter groups had improved feed efficiency, the authors suggested that protein availability may have been lower for the control group and any benefits from feeding litter silage may be biased. The digestible protein level for the control ration is lower than all the other rations (Table G-22).

There were no significant correlations between any of the animal response parameters of steers and ensiled broiler litter ration content when expressed in kilograms. However, when expressed as a percent change from the control, both feed consumption per day and average daily gain were correlated to litter content (Figure 30). These animal performance results are very limited and variable and only include four data points. Therefore, additional studies are required to clearly determine any animal performance benefits for utilizing ensiled broiler litter as a feedstuff for steers. The maximum animal response level of incorporating broiler litter silage into steer rations that will neither increase nor decrease feed consumption per day may be 25%, and the maximum level for average daily gain may be 52%. There is insufficient information at this time to determine any "optimum" levels for ensiled broiler litter.

Economic Value Estimation

The economic estimation of the value of ensiled broiler litter as a feedstuff for ruminants (based on feed costs, animal cost and selling price, and economic return) is shown in Tables 65 and 66.

Feed costs per tonne and per kilogram of gain were reduced for both litter groups in the study by McClure et al. (1977). In contrast to the negative control group, feed costs per day and total feed costs increased for the 12.8% litter group. This may be attributed to the large increase in feed consumption per day for the litter group. In contrast to the positive control group, the 12.8% litter group had lower feed costs per day and total

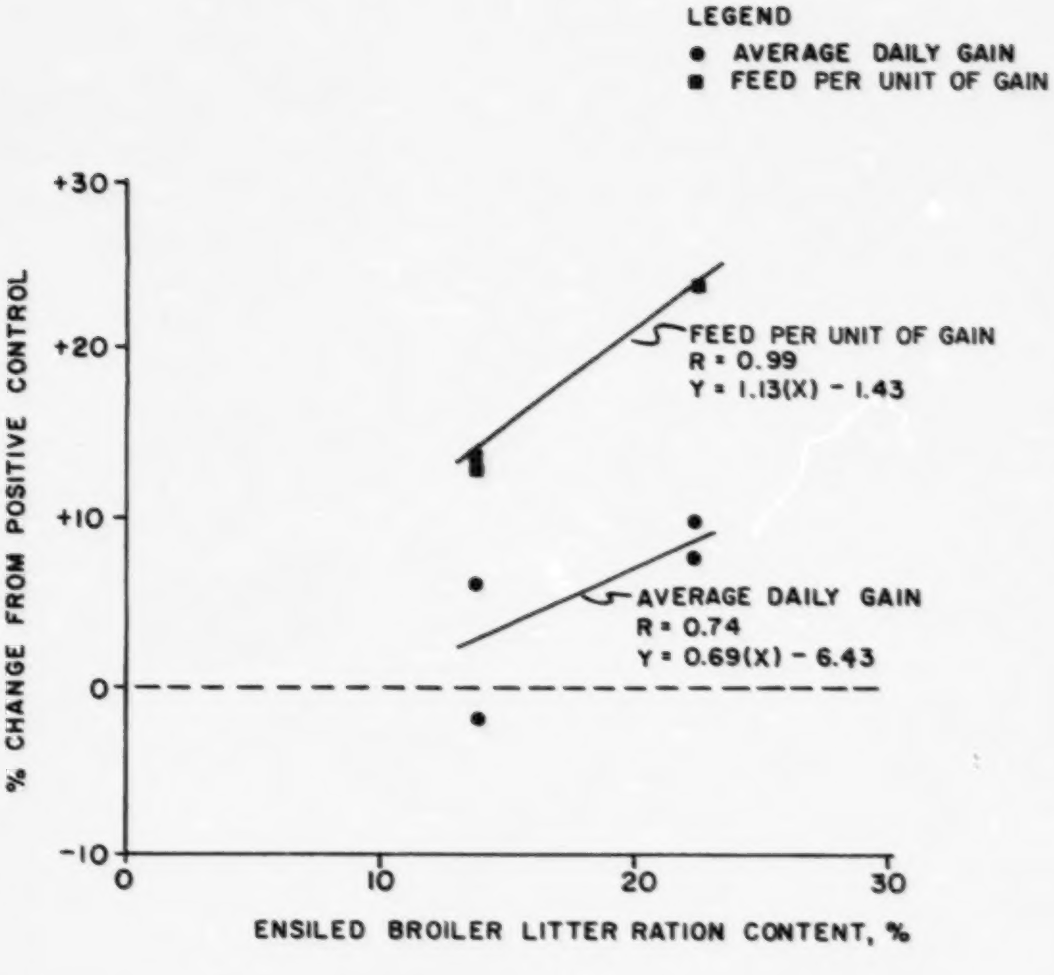

Figure 29. Relationships Between Ensiled Broiler Litter Ration Content, Average Daily Gain, and Feed Consumption Per Unit of Body Weight Gain For Heifers Fed Ensiled Broiler Litter

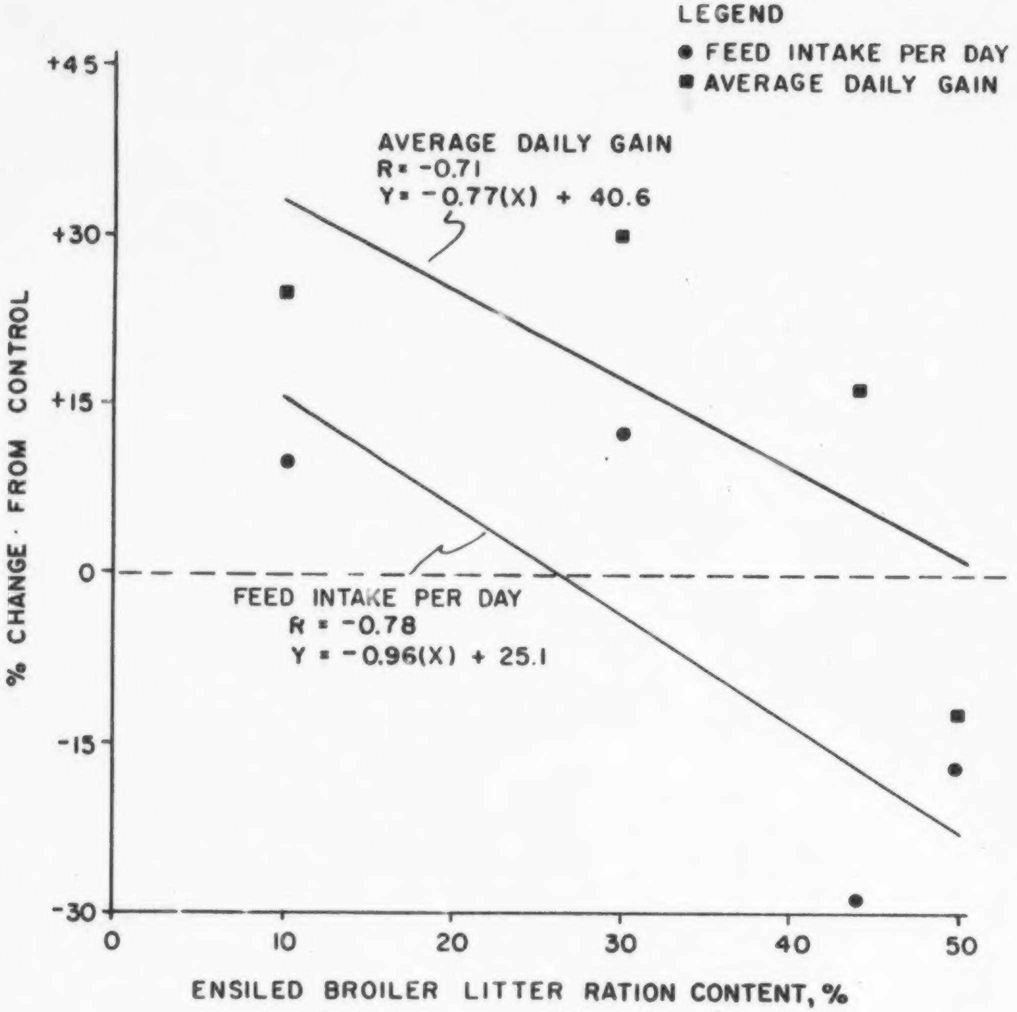

Figure 30. Relationships Between Ensiled Broiler Litter Ration Content, Average Daily Gain, and Feed Consumption Per Day For Steers Fed Ensiled Broiler Litter

TABLE 65. ECONOMIC ESTIMATE OF THE VALUE OF ENSILED BROILER LITTER AS A FEEDSTUFF FOR RUMINANTS (dollar)

Source	Feed Cost Per Tonne	Feed Cost Per Day	Feed Cost Per Kilogram Gain	Animal Cost	Total Feed Cost	Animal Selling Price	Economic Return	Gross Value Per Tonne of Litter
Heifers								
McClure *et al.* (1977)								
Negative Control	48.90	0.4126	0.7712	329.05	82.52	505.97	94.40	--
12.8% litter	35.60	0.5297	0.5789	362.12	105.94	664.71	196.65	268.44* 30.24†
Positive Control	47.00	0.6204	0.6635	327.39	124.08	636.60	185.13	--
12.8% litter & SBM ‡	42.50	0.6362	0.6426	355.50	127.24	682.90	200.16	39.22
McClure *et al.* (1978)								
Negative Control	43.00	0.5266	0.6533	415.52	90.05	643.54	137.97	--
22.3% litter	35.00	0.5446	0.5403	417.84	93.13	702.74	191.77	90.68* 63.59†
Positive Control	51.90	0.6521	0.6945	422.97	111.51	688.52	154.04	--
22.3% litter & SBM ‡	41.30	0.6425	0.6244	414.70	109.87	705.71	181.14	45.68

(continued)

TABLE 65. (continued)

Source	Feed Cost Per Tonne	Feed Cost Per Day	Feed Cost Per Kilogram Gain	Animal Cost	Total Feed Cost	Animal Selling Price	Economic Return	Gross Value Per Tonne of Litter
Steers								
Cross et al. (1978)								
Control	59.90	0.4852	0.6739	351.85	97.04	574.07	125.18	--
10% litter	58.40	0.5198	0.5776	367.28	103.96	645.06	173.82	273.26
30% litter	37.90	0.3449	0.3669	359.57	68.98	649.69	221.14	175.75
70 to 44% litter	57.60	0.3110	0.3702	339.50	62.20	598.76	197.06	151.26
50% litter	35.00	0.2345	0.3722	344.13	46.90	538.58	147.55	33.39

*[1] Compared to negative control group

†[2] Compared to positive control group

‡ Soybean meal

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TABLE 66. ECONOMIC ESTIMATE OF THE VALUE OF ENSILED BROILER LITTER AS A FEEDSTUFF FOR RUMINANTS (percent change from the control)

Source	Ration	Feed Cost Per Tonne	Feed Cost Per Day and Total Feed Cost	Feed Cost Per Kilogram Gain	Animal Cost	Animal Selling Price	Economic Return
Heifers							
McClure *et al.* (1977)	12.8% litter vs 1*	-27.2	+28.4	-24.9	+10.0	+31.4	+108.3
	12.8% litter vs 2†	-24.3	-14.6	-12.7	+10.6	+ 4.5	+ 8.1
	12.8% litter & SBM ‡	- 9.6	+ 2.5	- 3.1	+ 8.6	+ 7.3	+ 6.2
McClure *et al.* (1978)	22.3% litter vs 1*	-18.6	+ 3.4	-17.3	+ 0.6	+ 9.2	+39.0
	22.3% litter vs 2†	-32.6	-16.5	-22.2	- 1.2	+ 2.1	+24.5
	22.3 litter & SBM ‡	-20.4	- 1.5	-10.1	- 2.0	+ 2.5	+17.6
Steers							
Cross *et al.* (1978)	10% litter	- 2.5	+ 7.1	-14.3	+ 4.4	+12.4	+38.9
	30% litter	-36.7	-28.9	-45.6	+ 2.2	+13.2	+76.7
	70 to 44% litter	- 3.8	-35.9	-45.1	- 3.5	+ 4.3	+57.4
	50% litter	-41.6	-51.7	-44.8	- 2.2	- 6.2	+17.9

*1 Compared to negative control group
†2 Compared to positive control group
‡ Soybean meal

feed costs. However, these costs increased slightly for the 12.8% litter plus soybean meal group. Both the animal selling price and economic return are increased for both litter groups. In contrast to the negative control group, the large increase in economic return for the 12.8% litter group reflects the increased animal selling prices and not feed cost savings. In contrast to the positive control group, the increased economic return for the 12.8% litter group reflects both feed cost savings and increased animal selling prices. The increased economic return for the 12.8% litter plus soybean meal group reflects only increased animal selling prices and not feed cost savings. The calculated gross value of litter is artificially high due to the poor performance of the negative control group and does not reflect its true value. The calculated value should be computed on the performance of the positive control group and the value of $30-39 per tonne reflects the value of ensiled broiler litter used in this study.

Similarly, feed costs per tonne and per kilogram of gain were lower for both litter groups in the study by McClure *et al.* (1978). Feed costs per day and total feed costs were higher for the 22.3% litter group, when compared to the negative control group, but were lower for both litter groups when compared to the positive control group. Both the animal selling price and economic return were greater for the litter groups. The increased economic return for the 22.3% litter group, in contrast to the negative control group, reflects the increased animal selling price and not feed cost savings. In comparison to the positive control group, the higher economic return for both litter groups reflects both increased animal selling prices and feed cost savings. The calculated gross value of $46-64 per tonne, when computed against the performance of the positive control group, reflects the value of ensiled broiler litter utilized as a feedstuff for heifers for this study.

The economic assessment results were statistically analyzed, but the data base is insufficient to determine any significant maximum or "optimum" levels of incorporating ensiled broiler litter into heifer rations.

The economic assessment of the study by Cross *et al.* (1978) is confounded by the poor performance of the control group which was attributed to the low protein availability of their ration. Therefore, feed cost savings, increased animal selling prices and increased economic returns are artificially high, and the calculated gross value of the ensiled litter does not reflect its true value.

Discussion

The practice of ensiling broiler litter with corn silage has been suggested as a method to: (1) increase palatability; (2) increase the protein content of the corn silage; (3) reduce nutrient losses; (4) permit stockpiling of litter and thereby reduce handling costs; (5) control harmful pathogens; (6) deodorize the litter; and (7) increase economic returns.

The protein content of ensiled broiler litter silage has been reported to be approximately double that of corn silage (Couch, 1974). Studies by McClure *et al.*, (1977, 1978) reported a 48% increase in protein content of corn-litter silage. McClure et al. (1977, 1978) suggested that feeding litter silage to heifers will result in similar animal performance as heifers fed a typical silage ration plus a protein supplement.

The evaluation of animal performance in this section indicated that heifers fed ensiled litter will have an increase in all feed consumption parameters and usually increase their total weight gains. The increase in feed consumption per day was equivalent to the litter content in the rations and suggests that the litter may have had a dilution effect. However, body weights generally increased for the litter fed-heifers indicating that they were able to utilize some of the nutrients in the litter. Therefore, the ensiled broiler litter acted as more than a diluent.

The economic assessment indicated that the increased feed consumption reduced and in some cases negated potential feed cost savings. The substantial feed cost savings suggested by the authors were not realized and this is reflected in the low gross value of the litter ($30-64 per tonne). The gross value does not reflect any handling, transportation or ensiling costs.

The evaluation of animal performance and the economic assessment of utilizing broiler litter silage as a feedstuff in finishing steer rations (Cross et al. 1978) was confounded by the poor performance of the control group. Incorporating 50 or 70% litter silage into a ration resulted in palatability problems. The authors suggest that broiler litter can be a replacement for corn silage up to and including at least 30%, with no deleterious effects upon carcass or organoleptic quality. The animal response indicates that the maximum level of utilizing litter silage is 30%, on the basis of feed efficiency. However, on the basis of average daily gain, the maximum level is 43%. Additional investigations are needed to fully evaluate the practice of utilizing ensiled broiler litter as a feedstuff in steer rations because the current state of the art prohibits delineation of its benefits.

In summary, any benefits from utilizing ensiled broiler litter as a feedstuff for heifers and steers cannot be clearly delineated at this time. Although animal response indicates that possible benefits exist, they are confounded by the abnormal performance of the control groups and the limited data base. Identifying maximum and "optimum" levels of incorporating ensiled broiler litter into ruminant rations must await the results of future feeding trials.

COMPOSTED BROILER LITTER FED TO RUMINANTS

Composted broiler litter used as a feedstuff for beef heifers and brood cows has been extensively studied by Webb et al. (1974, 1975, 1977, and 1978) and these studies were evaluated (Table G-24). The composition of the various control and litter rations is shown in Table G-25. Generally, incorporation of composted broiler litter into the rations increased crude and digestible protein, ether extract, ash, calcium, phosphorus, and TDN, and decreased crude fiber and metabolizable energy levels. Copper (Cu) was added to one litter ration in each study to determine if copper toxicity would be encountered. The litter used was removed from broiler houses bedded with wood shavings and was stacked in an open shed for an unspecified time period prior to feeding.

Two-thirds of the original 42 beef heifers in the study by Webb et al. (1974) were fed the litter ration during the winter months and placed on pasture the remainder of the year. The study with the original 33 brood cows (Webb et al., 1974) was conducted during the two winters (1970 to 1972) when the litter rations were fed. The remaining time the cows were on pasture.

The rations for the heifers and cows were fed in such amounts as to supply the TDN requirements for growing heifers and pregnant cows. Additional hay was added to the litter rations in 1977-1978 due to a poor grazing season and the cows entered the winter in a thin condition. The additional hay is calculated into the feed intake data in the animal performance evaluation.

Animal Performance Evaluation

The performance of beef heifers (feed consumption per day, per kilogram of gain and total feed, average daily gain, total weight gain, and calving) fed composted broiler litter is shown in Tables 67 and 68. The performance of brood cows (feed consumption per day and total feed, calving and calf weights) fed composted broiler litter is shown in Tables 69 and 70.

There were no significant differences between rations containing composted litter or composted litter plus copper in any of the seven studies. Copper content in the liver of the copper supplementation animals was higher than that of the animals fed litter with no supplementation or the control animals. The copper levels decreased during the summer when all animals were on pasture.

The utilization of composted broiler litter in growing beef heifer wintering rations significantly improved feed efficiency and body weight gains and had no harmful effects upon calving or calf birth weights (Tables 67 and 68). This increased performance is not unexpected because the nutrient content of their ration was higher than the control rations (Table G-25). The control ration composition was high in hay while the litter rations contained ear or shell corn. The rations were fed in such amounts as to supply the TDN requirements. However, this practice is questionable (Ensminger and Olentine, 1978; Van Soest, 1980). Furthermore, the daily intake of digestible protein was 41-66% greater for the litter fed heifers than the controls. To evaluate the value of composted broiler litter, the control rations should be nutritionally equivalent to the litter rations.

The use of composted broiler litter in wintering rations of pregnant brood cows previously raised on composted broiler litter as heifers did not significantly affect their performances, according to the authors (Tables 69 and 70). These results indicate that pregnant brood cows were able to utilize the nutrients in composted litter when they constitute as much as 67 to 80% of the ration.

No correlations between any of the animal response parameters and the composted litter ration were apparent. Therefore, any maximum or "optimum" animal response levels of incorporation into a ration cannot be determined.

TABLE 67. PERFORMANCE OF BEEF HEIFERS FED COMPOSTED BROILER LITTER AS A FEEDSTUFF (kilograms)

Source	Feed Consumption Per Day	Feed Per Kilogram Of Gain	Average Daily Gain	Total Weight Gain	Number Of Calves Born	Percent Calving	Calf Birth Weight	Total Feed Consumed	Total Litter Consumed
Webb *et al*. (1974)									
Control	5.579	21.213	0.263	34.2	-	-	-	725.3	-
50% litter	5.171	13.572	0.381	49.5	-	-	-	672.2	336.1
50 % litter & Cu*	6.078	14.897	0.408	53.0	-	-	-	790.1	395.0
Control	7.484	31.183	0.240	23.5	-	-	-	733.4	-
75% litter	7.303	15.183	0.481	47.1	-	-	-	715.7	536.8
75% litter & Cu*	7.802	15.794	0.494	48.4	-	-	-	764.6	573.4
Webb *et al*. (1975)									
Control	6.577	-	-0.562	-	11	78.6	29.03	920.8	-
75% litter	5.897	-	-0.617	-	12	85.7	29.94	825.6	619.2
75% litter & Cu*	5.806	-	-0.508	-	14	100	30.39	812.8	609.6

* Copper

TABLE 68. PERFORMANCE OF BEEF HEIFERS FED COMPOSTED BROILER LITTER AS A FEEDSTUFF (percent change from the control)

Source	Feed Consumption Per Day and Total Feed Consumed	Feed Per Kilogram Gain	Average Daily Gain and Total Weight Gain	Number of Calves Born and Percent Calving	Calf Birth Weight
Webb *et al*. (1974)					
50% litter	- 7.3	-36.0	+ 44.9	-	-
50% litter & Cu*	+ 8.9	-29.8	+ 55.1	-	-
75% litter	- 2.4	-51.3	+100.4	-	-
75% litter & Cu	+ 4.2	-49.4	+105.8	-	-
Webb *et al*. (1975)					
75% litter	-10.3	-	- 9.8	+ 9.1	+3.1
75% litter & Cu*	-11.7	-	+ 9.6	+27.3	+4.7

* Copper

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TABLE 69. PERFORMANCE OF BROOD COWS FED COMPOSTED BROILER LITTER AS A FEEDSTUFF (kilograms)

Source	Feed Consumption Per Day	Number Of Calves Born	Percent Calving	Calf Birth Weight	Total Feed Consumed	Total Litter Consumed
Webb et al. (1974)						
Control	8.165	7	63.6	32.7	1102.3	-
80% litter	7.484	6.4	58.5	34.5	1010.3	808.2
80% litter & Cu*	7.484	7.7	69.7	33.6	1010.3	808.2
Webb et al. (1977)						
Control	7.802	14	100	30.4	928.4	-
80% litter	6.260	13	91.7	32.2	744.9	595.9
80% litter & Cu*	7.076	14	100	31.7	842.0	673.6
Control	9.843	10	83.3	31.7	1092.6	-
72.4% litter	9.480	10	83.3	31.7	1052.3	761.9
72.4% litter & Cu*	9.979	7	58.3	32.2	1107.7	802.0
Webb et al. (1978)						
Control	9.117	-	-	-	1084.9	-
66.7% litter	7.983	-	-	-	950.0	633.6
66.7% litter & Cu*	8.346	-	-	-	993.2	662.5

* Copper

TABLE 70. PERFORMANCE OF BROOD COWS FED COMPOSTED BROILER LITTER AS A FEEDSTUFF (percent change from the control)

Source	Feed Consumption Per Day and Total Feed Consumption	Number of Calves Born and Percent Calves	Calf Birth Weight
Webb *et al*. (1974)			
80% litter	- 8.3	- 8.6	+5.5
80% litter & Cu*	- 8.3	+10.0	+2.8
Webb *et al*. (1977)			
80% litter	-19.8	- 7.1	+6.0
80% litter & Cu*	- 9.3	0	+4.5
72.4% litter	- 3.7	0	0
72.4% litter & Cu*	+ 1.4	-30.0	+1.4
Webb *et al*. (1978)			
66.7 litter	-12.4	-	-
66.7% litter & Cu*	- 8.5	-	-

* Copper

Economic Value Estimation

The economic estimation of the value of composted broiler litter as a feedstuff for beef heifers and brood cows (based on feed cost per tonne, per day, per kilogram of gain, per calf and total, and feed cost savings) is shown in Tables 71 and 72.

All feed cost parameters were lower for the composted-litter-fed heifers and cows, in a direct relationship with litter content in the ration. Feed cost savings were higher for the cows than the heifers ($51.46 versus $35.49), which is attributed to the higher litter content in the cow rations. The estimated gross value of composted broiler litter for all the evaluated studies was similar for both the heifers and the cows ($80.69 and $72.24, respectively). The results of the economic evaluation of utilizing composted broiler litter as a feedstuff for beef heifers and brood cows indicate that economic incentives may exist to reduce feed costs.

Discussion

The utilization of composted broiler litter in wintering rations for beef heifers and pregnant brood cows has been reported only by Webb *et al*. (1974; 1977; 1978), and their results have not been indepently confirmed. The evaluation of these studies has been hampered because of incomplete and/or confusing reported results. The nutrient composition of the composted broiler litter, the composting duration and the influence of composting on litter nutritive value were not reported. Also, from a nutritional basis, comparing the performance of cattle fed a 100% forage ration to the performance of cattle fed forage and corn grain ration, may be inappropriate.

Despite the problems encountered in the evaluation of these studies, the utilization of composted broiler litter appears to offer animal performance benefits and economic incentives. Beef heifers and brood cows fed composted broiler litter appear to have an enhanced or at least similar animal performance as cattle fed a hay ration. In the cited studies (Webb *et al*. (1974, 1977, and 1978) no detrimental effects were observed.

The economic incentive offered by this practice is substantially reduced feed costs. Transportation, handling and composting costs must be subtracted from the estimated gross value of composted broiler litter determined by this section.

SUMMARY OF BROILER LITTER FEEDING TRIAL EVALUATIONS

The results of the evaluation of animal performance and the economic assessment of the utilization of broiler litter as a feedstuff for ruminants are summarized in Table 73. Maximum levels of incorporation that will neither enhance or adversely affect animal performance vary with respect to the type of processing used for the litter (as collected, dried, ensiled, or composted). Economic levels of incorporation could not be determined because of conflicting animal performance results and limited data bases.

TABLE 71. ECONOMIC ESTIMATE OF THE VALUE OF COMPOSTED BROILER LITTER AS A FEEDSTUFF FOR BEEF HEIFERS AND BROOD COWS (dollars)

Source	Ration	Feed Cost Per Tonne	Feed Cost Per Per Day	Feed Cost Per Kilogram Gain	Total Feed Cost	Feed Cost Per Calf	Feed Cost Savings	Gross Value Per Tonne of Litter
Heifers								
Webb *et al.* (1974)	Control	79.80	0.4452	1.6928	57.88	-	-	-
	50% litter	35.80	0.1851	0.4858	24.06	-	33.82	100.62
	50% litter & Cu*	35.80	0.2176	0.5333	28.29	-	29.59	74.91
	Control	71.60	0.5359	2.2329	52.52	-	-	-
	75% litter	17.90	0.1307	0.2718	12.81	-	39.71	73.98
	75% litter & Cu*	17.90	0.1397	0.2828	13.69	-	38.83	67.72
Webb *et al.* (1975)	Control	71.60	0.4709	-	65.93	83.91	-	-
	75% litter	17.90	0.1056	-	14.78	17.25	51.51	82.61
	75% litter & Cu*	17.90	0.1039	-	14.55	14.55	51.38	84.28
Cows								
Webb *et al.* (1974)	Control	71.60	0.5846	-	78.92	124.02	-	-
	80% litter	21.30	0.1594	-	21.52	36.99	57.40	71.02
	80% litter & Cu*	21.30	0.1594	-	21.52	30.74	57.40	71.02
Webb *et al.* (1977)	Control	71.60	0.5586	-	66.47	66.47	-	-
	80% litter	21.30	0.1333	-	15.86	17.08	50.61	84.93
	80% litter & Cu*	21.30	0.1507	-	17.93	17.93	48.54	72.06
	Control	71.60	0.7048	-	78.23	93.88	-	-
	72.4% litter	26.10	0.2474	-	27.46	32.95	50.77	66.64
	72.4% litter & Cu*	26.10	0.2605	-	28.92	49.58	49.31	61.48
Webb *et al.* (1978)	Control	71.60	0.6528	-	77.68	-	-	-
	66.7% litter	29.70	0.2371	-	28.21	-	49.47	78.08
	66.7% litter & Cu*	29.70	0.2479	-	29.50	-	48.18	72.72

* Copper

TABLE 72. ECONOMIC ESTIMATE OF THE VALUE OF COMPOSTED BROILER LITTER AS A FEEDSTUFF FOR BEEF HEIFERS AND BROOD COWS (percent change from the control)

Source	Ration	Feed Cost Per Tonne	Feed Cost Per Day, Total Feed Cost, and Feed Cost Savings	Feed Cost Per Kilogram Of Gain	Feed Cost Per Calf
Heifers					
Webb et al. (1974)	50% litter	-55.1	-58.4	-71.3	-
	50% litter & Cu *	-55.1	-51.1	-68.5	-
	75% litter	-75.0	-75.6	-87.8	-
	75% litter & Cu *	-75.0	-73.9	-87.3	-
Webb et al. (1975)	75% litter	-75.0	-77.6	-	-79.4
	75% litter & Cu *	-75.0	-77.9	-	-82.7
Cows					
Webb et al. (1974)	80% litter	-70.3	-72.7	-	-70.2
	80% litter & Cu *	-70.3	-72.7	-	-75.2
Webb et al. (1977)	80% litter	-70.3	-76.1	-	-74.3
	80% litter & Cu *	-70.3	-73.0	-	-73.0
	72.4% litter	-63.5	-64.9	-	-64.9
	72.4% litter & Cu *	-63.5	-63.0	-	-47.2
Webb et al. (1978)	66.7% litter	-58.5	-63.7	-	-
	66.7 & litter & Cu *	-58.5	-62.0	-	-

* Copper

TABLE 73. SUMMARY OF THE MAXIMUM ANIMAL RESPONSE LEVELS OF INCORPORATING BROILER LITTER INTO RUMINANT RATIONS AND THE ESTIMATED ECONOMIC VALUE OF THE LITTER

Treatment	Species Fed	Maximum Animal Response Level, %	Estimated Gross Value Per Tonne
As Collected	Steers	18-22	\$72
Dried	Steers	11-16	\$90
Ensiled	Steers	25-52	-
	Heifers	1-10	\$90*
Composted	Heifers	∿75	\$81
	Cows	∿80	\$72

* Estimated gross value compared to positive control groups equals \$45 per tonne; value compared to negative control groups equals \$180 per tonne; the \$90 per tonne represents the mean of all the observations.

SECTION 9

NUTRITIVE AND ECONOMIC VALUE OF DAIRY COW AND BEEF CATTLE MANURE BASED ON THE RESULTS OF FEEDING TRIALS

INTRODUCTION

This section attempts to identify the value of dairy cow and beef cattle manure as a feedstuff based on information from reported feeding trials. The methodology delineated in Section 7 was used to evaluate the nutritional information and to identify the economic costs and benefits.

DAIRY COW MANURE FEEDING TRIALS

An intensive review of the literature revealed few investigations utilizing dairy cow manure as a feedstuff. Some investigators reported feeding dried or ensiled dairy cow manure, but due to the lack of experimental design data and incomplete animal performance data, evaluation of the studies could not be done. A brief summary of these studies is shown in Table 74.

Palafox and Rosenberg (1951) included 0, 5, 10 or 15% dried cow feces into laying hen diets and concluded that feed consumption per hen day increased for all manure diets, and egg production decreased for the birds fed the 15% cow feces diet. Smith *et al.* (1969, 1971) conducted digestibility studies with dried cow manure, chemically treated or as collected, and concluded that nitrogen utilization decreased and intake was depressed for sheep receiving the manure rations. Smith and Gordon (1971) fed dried cow manure to heifers and reported depressed animal performance. Williams *et al.* (1974) ensiled fresh cow manure with corn and concluded that although efficiency costs were reduced for the manure fed steers, decreased body weight gains and lower resultant selling prices caused the economic return to be less than the control steers. Goering and Smith (1977) ensiled liquid cow manure with corn silage and reported improved animal performance for lambs fed this mixture.

The nutrient content of dairy cow manure is highly variable, and is influenced by the level of intake and the roughage to concentrate ratio in the ration (Fisher, 1974). Before the benefits for utilizing dairy cow manure as a feedstuff can be determined additional digestibility studies and feeding trials must be conducted.

TABLE 74. SUMMARY OF THE STUDIES UTILIZING DAIRY COW MANURE AS A FEEDSTUFF

Source	Type of Manure	Species Fed	Animal Performance Results
Palafox and Rosenberg (1951)	Dried	Laying Hens	5,10 and 15% increased feed consumption per bird-day. 15% decreased egg production.
Smith et al. (1969)	Dried	Sheep	Poor nitrogen utilization.
Smith et al. (1971)	Dried	Sheep	Depressed intake.
Smith and Gordon (1971)	Dried	Heifers	Decreased animal performance.
Williams et al. (1974)	Ensiled	Steers	Depressed body weight gains.
Goering and Smith (1977)	Ensiled	Lambs	Improved animal performance when compared to ration containing corn silage, urea and soybean meal.

BEEF CATTLE MANURE

A total of 35 studies were identified that involved the direct utilization of beef cattle manure as a feedstuff for cattle. Twelve of these studies fulfilled the evaluation criteria stated in Section 7 and were evaluated in this section.

AS COLLECTED OR DRIED BEEF CATTLE MANURE FED TO STEERS AND HEIFERS

The utilization of as collected or dried beef cattle manure as a feedstuff to growing and finishing ruminants has been investigated in 13 studies. Only four studies fulfilled the selection criteria and were evaluated (Table G-26). The composition of the rations utilized in the four studies is shown in Table G-27. The composition, source and method of handling the cattle manure used in the four studies are noted in Table G-28. Generally, the incorporation of beef cattle manure into ruminant rations increased crude protein, ash, calcium and phosphorus, and decreased digestible protein, TDN and metabolizable energy levels.

Animal Performance Evaluation

The performance of steers and heifers (body weights, feed consumption and waste consumption) fed as collected or dried beef cattle manure as a feedstuff is shown in Tables 75 and 76.

In the first of three trials, Anthony (1966) added fresh, unwashed cattle manure to a high energy fattening steer ration at the ratio of 60 parts concentrate to 40 parts manure. Feed consumption per day, per kilogram of gain and total feed consumed was higher for the manure-fed steers, while their average daily gain and total body weight gain significantly decreased when compared to the controls. In the second trials, 28.7% fresh unwashed manure was added to a silage-concentrate steer ration. All feed consumption parameters increased and weight gain parameters decreased for the manure-fed steers. In the third trial, the manure-fed animals from trial 2 were fed a concentrate manure steer ration at a ratio of 60 parts concentrate to 40 parts manure. All feed consumption parameters significantly increased. Weight gain parameters significantly decreased for the manure-fed steers.

In the first of two trials, Anthony (1971) added feedlot manure to a concentrate fattening steer ration at the ratio of 60 parts concentrate to 40 parts manure and compared the performance of steers fed the manure ration to control steers fed a concentrate ration supplemented with cottonseed meal and molasses. All feed consumption parameters were significantly higher, while body weight parameters were slightly lower for the manure-fed steers. In the second trial, the same manure ration was fed, but the control ration was supplemented with urea. Feed consumption per day was slightly higher, feed efficiency was similar, and body weight gains were greater for the manure fed steers when compared to the controls. This improved performance by the manure fed steers is misleading due to a reduced animal performance of the control steers. The urea-supplemented control ration was unpalatable and the steers drooled excessively throughout the trial.

There were no significant correlations between any of the animal response parameters and manure content. From an animal response basis, the feeding of as collected beef cattle manure to steers decreased body weight gains, lowered feed efficiency, increased feed consumption per day, and appears not to be a sound nutritional practice.

The performance of yearling calves (4 heifers and 2 steers per group) fed dried feedlot manure was reported by Johnson *et al.* (1975a). Animal performance results are expressed as the average of the heifers and steers in each group. In the first experimental group, 15% manure replaced all of the cottonseed hulls in the control ration; in the second group, 10% manure replaced two-thirds of the cottonseed hulls; and in the third group 15% manure replaced two-thirds of the cottonseed hulls and most of the soybean meal in the control ration. Feed consumption per day decreased for all manure-fed calves, indicating a possible palatability problem. Both feed efficiency and body weight gains were significantly lower for all three manure-fed groups.

TABLE 75. PERFORMANCE OF STEERS AND HEIFERS FED AS COLLECTED OR DRIED BEEF CATTLE MANURE AS A FEEDSTUFF (kilograms)

Source	Ration	Initial Weight	Final Weight	Weight Gain	Average Daily Gain	Feed Consumption Per Day	Feed Consumption Per Kg Gain*	Total Feed Consumed	Total Waste Consumed
As Collected									
Anthony (1966)	Control	250	434.7	184.7	0.957	9.962	10.41	1922.7	-
	40% Manure	250	411.2	161.2	0.835	10.245	12.27	1977.3	790.9
	Control	250	340	90.0	0.703	12.267	17.45	1570.2	-
	28.7% Manure	250	327.8	77.8	0.608	15.668	25.77	2005.5	575.6
	Control	340	432.1	92.1	0.98	7.693	7.85	723.1	-
	40% Manure	327.8	386.6	58.8	0.626	10.861	17.35	1020.9	408.4
Anthony (1971)	Control	285	410	125	1.225	8.991	7.34	917.1	-
	40% Manure	283	405	122	1.196	12.733	10.61	1298.8	519.5
	Control	337	444	107	0.793	10.649	13.48	1437.6	-
	40% Manure	336	448	112	0.83	11.097	13.37	1478.1	599.2
Dried									
Johnson et al. (1975a)	Control	250	359.8	109.8	1.207	8.664	7.18	788.4	-
	15% Manure w/o hulls †	250	316.1	66.1	0.726	8.165	11.25	743.0	111.4
	10% Manure	250	340.4	90.4	0.993	7.802	7.86	710.0	71.0
	15% Manure w/o SBM ‡	250	326.8	76.8	0.844	8.074	9.57	734.7	110.2
Lowrey et al. (1975)	Control 1	330	456.4	126.4	1.29	10.03	7.76	982.9	-
	Control 2	330	445.6	115.6	1.18	9.90	8.39	970.2	-
	20% Manure	330	431.9	101.9	1.04	9.95	9.57	975.1	195.0

* Calculated: feed consumption per day ÷ average daily gain
† without cottonseed hulls
‡ without soybean meal

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TABLE 76. PERFORMANCE OF STEERS AND HEIFERS FED AS COLLECTED OR DRIED BEEF CATTLE MANURE AS A FEEDSTUFF (percent change from the control)

Source	Ration	Initial Weight	Final Weight	Total Weight Gain and Average Daily Gain	Feed Consumption Per Day and Total Feed Consumed	Feed Consumption Per Kilogram Gain
As Collected						
Anthony (1966)	40% Manure	0	- 5.4	-12.7	+ 2.8	+ 17.9
	28.7% Manure	0	- 3.6	-13.6	+27.7	+ 47.7
	40% Manure	-3.6	-10.5	-36.2	+41.2	+121.0
Anthony (1971)	40% Manure	-0.7	- 1.2	- 2.4	+41.6	+ 44.6
	40% Manure	-0.3	+ 0.9	+ 4.7	+ 4.2	- 0.8
Dried						
Johnson *et al.* (1975a)	15% Manure w/o hulls*	0	-12.1	-39.8	- 5.8	+ 56.7
	10% Manure	0	- 5.4	-17.7	- 9.9	+ 9.5
	15% Manure w/o SMB †	0	- 9.2	-30.1	- 6.8	+ 33.3
Lowrey *et al.* (1975)	20% Manure vs 1	0	- 5.4	-19.4	- 0.8	+ 23.3
	vs 2	0	- 3.1	-11.9	+ 0.5	+ 14.1

* without cottonseed hulls

† without soybean meal

Lowrey et al. (1975) added 20% dried cattle feedlot manure to a yearling steer ration and compared their performance to two control rations. Control ration (1) was supplemented with 8% soybean meal, and control ration (2) was supplemented with 4% soybean meal. Feed consumption per day for the manure group was similar to that of both control groups. Feed efficiency and weight gains were significantly reduced for the manure group and were most reduced when compared to control group (1).

Correlations were not determined for feed efficiency or average daily gain (expressed as a percent change from the control) and dried manure ration content (Figure 31) due to variation between the evaluated studies. Correlations were determined for both parameters when they are expressed in kilograms. As the dried manure ration content increased, kilograms of feed per kilogram of gain increased, and average daily gain decreased (Figure 32). The evaluation of the practice of utilizing dried beef cattle manure as a feedstuff indicates that the performance of steers and heifers is likely to be adversely affected by any level of manure added to the ration.

Economic Value Estimation

The economic estimation of the value of as collected or dried beef cattle manure as a feedstuff for steers and heifers (based on feed costs, animal cost and economic return) is presented in Tables 77 and 78.

In the first of three trials by Anthony (1966), all feed costs were reduced for the manure-fed steers. The economic return for these steers was larger than that of the control group and reflects only feed cost savings because the animal selling price was reduced. In the second trial, feed costs per tonne, per day and total feed costs were lower for the manure-fed steers. Efficiency costs were slightly higher than that of the controls. The decreased economic return by the manure-fed steers reflects the lower animal price that was not offset by feed cost savings. The economic results of the third trial were similar to those of the second trial. The calculated gross value of manure for all three trials was negative (-$27), indicating that economic benefits or incentives were not realized in this study.

All feed cost parameters were reduced for the manure-fed steers in the two trials reported by Anthony (1971). Because the controls in the second trials performed abnormally, any benefits determined for the manure-fed group are biased. The animal selling price was slightly lower for the manure-fed steers in trial 1 but were offset by feed cost savings, and the economic return increased. The estimated gross value of as collected cattle manure for trial 1 was $22.21. The $109.10 value for trial 2 represents an artificially high value due to the factors discussed above.

No correlations between any of the economic parameters and the as collected cattle manure content in the rations were observed. The average gross value of as collected cattle manure is negative (-$15/tonne, excluding trial 2 in 1971), and indicates no economic incentives or benefits for utilizing this type of manure as a feedstuff.

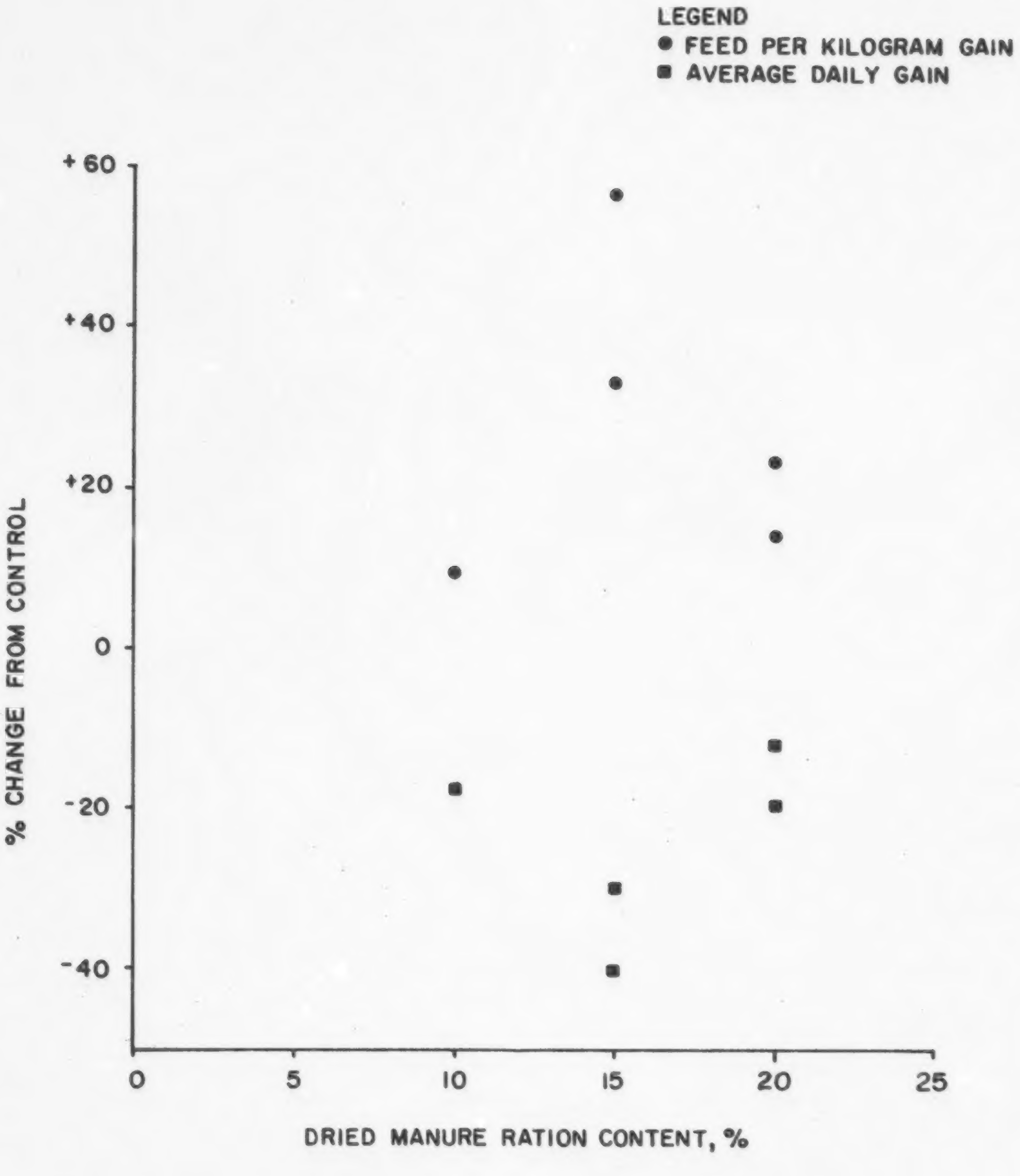

Figure 31. Relationship Between Dried Beef Cattle Manure Ration Content, Feed Per Kilogram of Gain, And Average Daily Gain For Ruminants Fed Dried Beef Cattle Manure

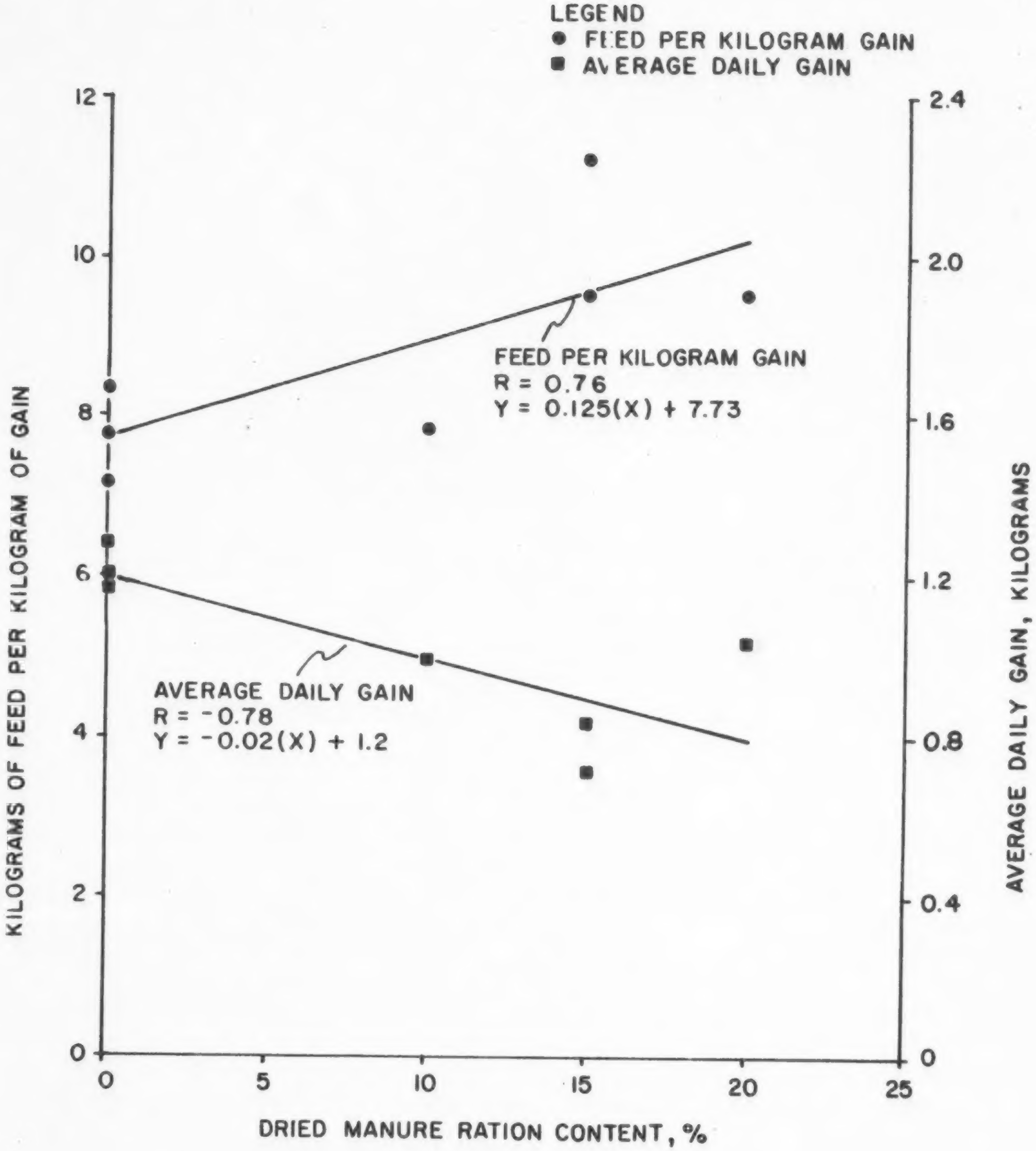

Figure 32. Relationship Between Dried Beef Cattle Manure Ration Content, Kilograms of Feed Per Kilogram of Gain, and Average Daily Gain For Ruminants Fed Dried Beef Cattle Manure

TABLE 77. ECONOMIC ESTIMATE OF THE VALUE OF AS COLLECTED OR DRIED BEEF CATTLE MANURE AS A FEEDSTUFF FOR STEERS AND HEIFERS (dollars)

Source	Ration	Feed Cost Per Tonne	Feed Cost Per Day	Feed Cost Per Gain	Animal Cost	Total Feed Cost	Animal Selling Price	Economic Return	Gross Value Manure Per Tonne
As Collected									
Anthony (1966)	Control	87.20	0.8687	0.9078	385.80	167.66	670.83	117.37	-
	40% Manure	52.30	0.5358	0.6417	385.80	103.41	634.56	145.35	35.38
	Control	44.30	0.5434	0.7730	385.80	69.56	524.69	69.33	-
	28.7% Manure	31.50	0.4935	0.8118	385.80	63.17	505.86	56.89	-21.61
	Control	114.40	0.8801	0.8980	524.69	82.72	666.82	59.41	-
	40% Manure	68.60	0.7451	1.1902	505.86	70.03	596.60	20.71	-94.76
Anthony (1971)	Control	117.30	1.0546	0.8610	439.81	107.57	632.71	85.33	-
	40% Manure	70.40	0.8964	0.7469	436.73	91.40	625.00	96.87	22.21
	Control	106.80	1.1373	1.4397	520.06	153.54	685.18	11.58	-
	40% Manure	64.00	0.7102	0.8557	518.52	95.88	691.35	76.96	109.10
Dried									
Johnson et al. (1975a)	Control	101.10	0.8759	0.7259	385.80	79.71	555.24	89.73	-
	15% Manure w/o hulls*	89.20	0.7283	1.0035	385.80	66.28	487.81	35.73	-484.74
	10% Manure	93.10	0.7264	0.7318	385.80	66.10	525.31	73.41	-229.86
	15% Manure w/o SBM†	92.40	0.7460	0.8843	385.80	67.89	504.32	50.63	-354.81
Lowrey et al. (1975)	Control 1	102.00	1.0231	0.7915	509.26	100.26	704.32	94.80	-
	Control 2	94.40	0.9346	0.7920	509.26	91.59	687.65	86.80	-
	20% Manure	89.40	0.8895	0.8556	509.26	87.17	666.51	70.08	vs 1-126.77 vs 2- 85.74

* Without cottonseed hulls
† Without soybean meal

TABLE 78. ECONOMIC ESTIMATE OF THE VALUE OF AS COLLECTED OR DRIED BEEF CATTLE MANURE AS A FEEDSTUFF TO STEERS AND HEIFERS (percent change from the control)

Source	Ration	Feed Cost Per Tonne	Feed Cost Per Day and Total Feed Cost	Feed Cost Per Kg Gain	Animal Cost	Animal Selling Price	Economic Return
As Collected							
Anthony (1966)	40% Manure	-40.0	-38.3	-29.3	0	- 5.4	+23.8
	28.6% Manure	-28.9	- 9.2	+ 5.0	0	- 3.6	-17.9
	40% Manure	-40.0	-15.3	+32.5	-3.6	-10.5	-65.1
Anthony (1971)	40% Manure	-40.0	-15.0	-13.3	-0.7	- 1.2	+13.5
	40% Manure	-40.1	-37.6	-40.6	-0.3	+ 0.9	+564.6
Dried							
Johnson et al. (1975a)	15% Manure w/o hulls*	-11.8	-16.9	+38.2	0	-12.1	-60.2
	10% Manure	- 7.9	-17.1	+ 0.8	0	- 5.4	-18.2
	15% Manure w/o SBM†	- 8.6	-14.8	+21.8	0	- 9.2	-43.6
Lowrey et al. (1975)	20% Manure						
	vs 1	-12.4	-13.1	+ 8.1	0	- 5.4	-26.1
	vs 2	- 5.3	- 4.8	+ 8.0	0	- 3.1	-19.3

* Without cottonseed hulls
† Without soybean meal

In the study by Johnson *et al.* (1975a), all feed costs were reduced for the dried manure-fed calves as compared to the control group, except that feed efficiency costs increased. The economic returns were lower for all three manure-fed groups, because the feed cost savings were unable to offset the reduced animal selling prices. Because of poor animal performance, the gross values of the dried manure utilized in this study were negative.

In the study by Lowrey *et al.* (1975), all feed costs for the manure-fed steers were lower than that of controls, with the exception of feed efficiency costs. The economic return of the manure-fed steers, in comparison to both control groups, was decreased because the feed cost savings did not offset the reduced animal selling prices. Because of poor animal performance by the manure-fed steers, the gross value of the dried manure was negative.

There were no correlations between any of the economic parameters and the dried cattle manure content in the ration. The average estimated gross value of dried cattle manure in all the evaluated studies was negative (-$256 per tonne) and indicated that no economic incentives or benefits appear to exist for utilizing this type of manure as a feedstuff.

Discussion

The reduced animal performance in the study by Anthony (1966) was attributed to a possible growth-inhibiting property in fresh cattle manure that could be removed by washing the manure prior to its incorporation into a ration. However, Anthony (1970) reported similar reduced animal performance when steers were fed rations containing washed or autoclaved cattle manure, suggesting that beef cattle manure is of low nutritive value as indicated by its nutrient characteristics.

In a later study, Anthony (1971) concluded that steers fed beef cattle manure consumed less of the basal ration and therefore feed cost savings could be realized. The evaluation of animal response revealed that more total ration (basal plus manure) was consumed by the manure-fed steers. When only the basal portion is considered, the manure-fed steers consumed less of the basal ration. However, the reduced weight gains and resultant selling price of the steers decreased the feed cost savings. This is reflected in the economic return of the manure-fed steers. The gross value of manure for this group, which reflects the differences in economic returns of the control and manure-fed steers, was only $22.21. When the cost of handling the manure and incorporating it into a ration is considered, the value of this manure may become negative.

The reduced animal performance reported in studies utilizing as collected cattle manure as a feedstuff might be attributed to its low digestibility, as reported by Albin and Sherrod (1975), Lucas *et al.* (1975), and Richter and Shirley (1977). The utilization of dried beef cattle manure as a feedstuff for calves indicated that it is not a good source of either roughage or nitrogen (Johnson *et al.* 1975a). Animal performance by the manure-fed steers in the study by Lowrey *et al.* (1975) was not comparable to control steers. Similar reduced animal performance has been reported by Westing *et al.* (1978).

In summary, the evaluation of animal performance and the economic assessment indicated that there are no apparent benefits or incentives for the utilization of as collected beef cattle manure as a feedstuff for ruminants. Similarly, from a nutritive and economic point-of-view, the utilization of dried beef cattle manure as a feedstuff for ruminants offers no benefits or incentives. This manure on a dry matter basis appears to have more value as a source of plant nutrients ($24 per tonne; Smith and Wheeler, 1979) than as a feedstuff.

ENSILED BEEF CATTLE MANURE FED TO RUMINANTS

The utilization of ensiled or composted beef cattle manure as a feedstuff for growing and finishing steers and heifers has been investigated in 22 studies. Only eight studies fulfilled the criteria and were evaluated (Table G-29). The composition of the rations fed in the evaluated studies is presented in Table G-30. Generally, the incorporation of cattle manure in rations increased crude protein, ash, calcium, phosphorus and crude fiber, and decreased TDN and metabolizable energy levels. The composition, source and treatment of the cattle manure utilized in the evaluated studies are shown in Table G-31.

Animal Performance Evaluation

The performance of ruminants (body weight gains, feed consumption, and manure consumption) fed ensiled beef cattle manure as a feedstuff, compared to corn silage fed controls, is shown in Tables 79 and 80.

The term "wastelage" has been developed by Anthony to describe an ensiled product containing 57 parts beef cattle manure and 43 parts ground coastal bermudagrass hay. The effects of substituting 40% wastelage for the corn silage in the control ration was studied by Anthony (1968). The ear corn content of the manure-fed steers was increased from 24% to 57% of the total ration. The manure content was 28% of the total ration and was evaluated at that level. The manure-fed steers, in contrast to the controls, had a higher feed consumption per day and total feed consumption, and lower feed efficiency. The final body weight, total weight gain and average daily gain were higher for the manure-fed steers.

Harpster et al. (1975) studied the effects of eliminating corn silage and soybean meal in the control ration and replacing them with 24, 41.7% or 60% cattle waste ensiled with timothy hay. The 60% manure ration contained no high moisture corn, the 41.7% manure ration corn content was comparable to that of the control, and the 24% manure ration had double the corn content of the control ration. All weight gain parameters decreased in an inverse relationship with the cattle waste content. Feed consumption per day was higher for the 24% manure fed group, but the increases diminished as the manure content increased suggesting a possible palatability problem. Feed efficiency decreased for all manure-fed steers in a direct relationship with the manure ration content.

TABLE 79. PERFORMANCE OF RUMINANTS FED ENSILED BEEF CATTLE MANURE AS A FEEDSTUFFS COMPARED TO CORN SILAGE FED CONTROLS (kilograms)

Source	Ration	Initial Weight	Final Weight	Weight Gain	Average Daily Gain	Feed Consumption Per Day	Feed Per Kilogram Of Gain	Total Feed Consumed	Total Manure Consumed
Anthony (1968)	Control	300	427.4	127.4	0.91	7.544	8.29	1056.2	-
	22.8% Manure	300	437.2	137.2	0.98	8.879	9.06	1243.1	283.4
Harpster et al. (1975)	Control	258	530	272	1.36	6.37	4.68	1274	-
	24% Manure	258	516	258	1.29	7.06	5.47	1412	338.9
	41.7% Manure	258	502	244	1.22	6.83	5.60	1366	569.6
	60% Manure	258	408	150	0.75	6.28	8.37	1256	753.6
Harpster et al. (1978)	Control	258	460	202	1.10	7.14	6.49	1306.6	-
	24% Manure	258	453	195	1.07	8.26	7.72	1511.6	362.8
	30% Manure	258	446	188	1.03	8.16	7.92	1493.3	448
	45% Manure	258	395	137	0.75	7.76	10.35	1420.1	639

TABLE 80. PERFORMANCE OF RUMINANTS FED ENSILED BEEF CATTLE MANURE AS A FEEDSTUFF COMPARED TO CORN SILAGE FED CONTROLS (percent change from the control)

Source	Ration	Initial Weight	Final Weight	Weight Gain and Average Daily Gain	Feed Consumption Per Day and Total Feed Consumed	Feed Consumption Per Kilogram of Gain
Anthony (1968)	22.8% Manure	0	+ 2.3	+ 7.7	+17.7	+ 9.3
Harpster et al. (1975)	24% Manure	0	- 2.6	- 5.1	+10.8	+16.9
	41.7% Manure	0	- 5.3	-10.3	+ 7.2	+19.7
	60% Manure	0	-23.0	-44.9	- 1.4	+78.8
Harpster et al. (1978)	24% Manure	0	- 1.5	- 3.5	+15.7	+19.0
	30% Manure	0	- 3.0	- 6.9	+14.3	+22.0
	45% Manure	0	-14.1	-32.2	+ 8.7	+59.5

In a second study, Harpster et al. (1978) eliminated the corn silage and soybean meal in the control ration and replaced them with three levels (24, 30 and 45%) of cattle manure ensiled with hay. For the 24% manure ration, the corn content was slightly higher than that of the control ration. For the 30% manure ration, the corn content was similar to that of the control ration and for the 45% manure ration the corn content was one half of that in the control ration. Animal performance was similar to that observed in the 1975 study. Weight gain and feed efficiency decreased as the manure ration increased, and feed consumption per day increased for all the manure rations. The increases were inversely related to the manure ration content.

There were no correlations between any of the animal response parameters (expressed in kilograms) and manure content. However, when the parameters are expressed as a percent change from the control, all the animal response parameters are significantly correlated to manure ration content. The utilization of ensiled cattle manure as a feedstuff significantly reduced average daily gain and total weight gains and significantly decreased feed efficiency (Figure 33). The maximum animal response level that will neither enhance nor adversely affect animal performance was 16-24%. However, this is purely mathematical because no evaluated studies utilized this level of cattle manure. From an animal response standpoint, the utilization of cattle manure ensiled with hay as a feedstuff for steers can depress animal performance and can cause palatability problems. Further experimentation is merited utilizing low levels of cattle manure (5 to 20%) ensiled with hay as a replacement for corn silage.

The performance of ruminants (body weight gains, feed consumption, and manure consumption) fed ensiled beef cattle manure as a feedstuff, compared to corn grain fed controls, are presented in Tables 81 and 82.

Anthony et al. (1969), in the first of two trials, mixed wastelage with whole shelled corn in the ratio of 2:3. This mixture contained 20.6% manure and was evaluated at this level. The manure-fed steers outperformed the controls in attaining higher final body weights, total weight gain and average daily gain, although their feed consumption per day increased significantly and their feed efficiency decreased. The control steers suffered from rumen parakeratosis, which might have biased the improved performance of the manure-fed group. In the second trial, the performance of steers fed rations containing 20, 40, or 60% wastelage (11.4, 22.8, or 34.2% manure) plus whole shelled corn and 40% wastelage (22.8% manure) plus ground shelled corn was compared to that of control steers. The performance of the wastelage-fed steers was not comparable to the controls because they attained lower body weight gains, had decreased feed consumption per day and a variable feed efficiency.

Anthony (1971), in the first of three trials, investigated the effects of feeding a 40% wastelage (21.1% manure) plus corn and cottonseed meal ration and a 40% wastelage (22.8% manure) plus corn ration to yearling steers. Performance of the manure-fed steers was comparable or superior to the controls in respect to body weight parameters. Their feed consumption per day significantly increased and feed efficiency significantly decreased. In the second trial, several wastelage rations were fed to steers, but there was no control

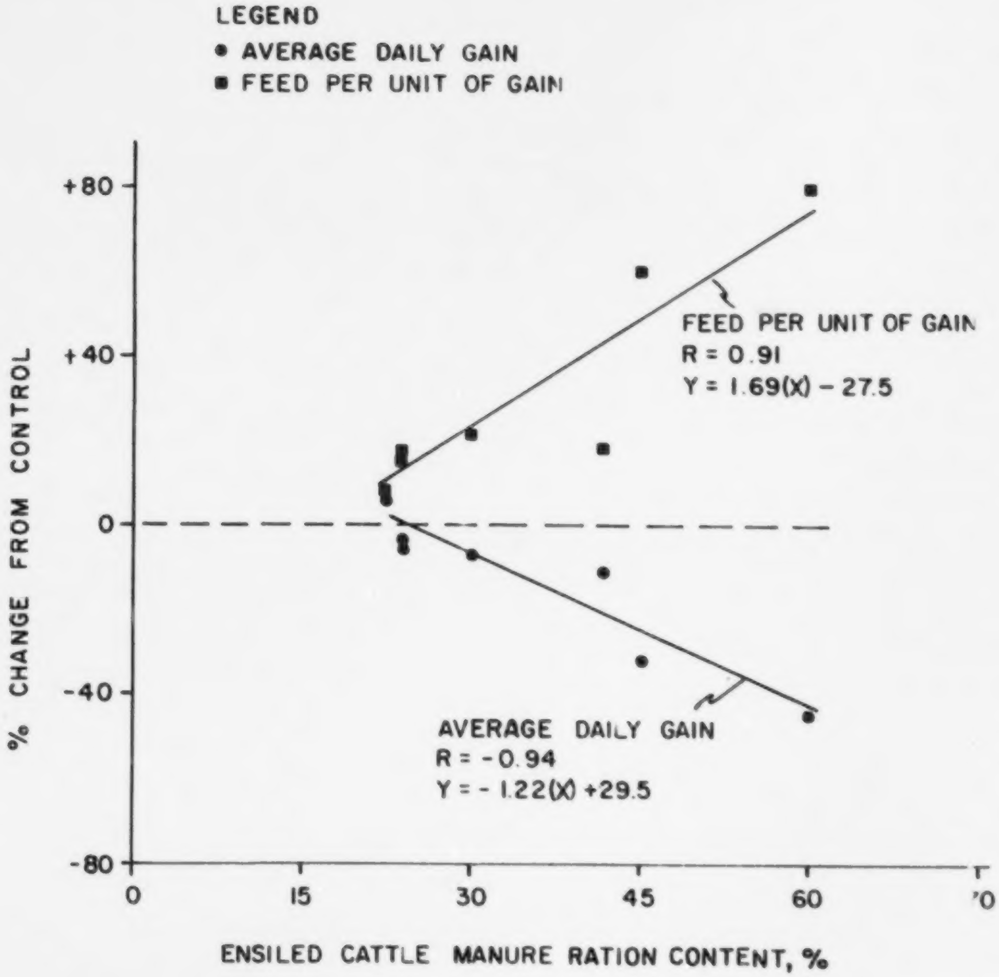

Figure 33. Relationships Between Ensiled Beef Cattle Manure Ration Content, Average Daily Gain, and Feed Consumption Per Unit of Body Weight Gain (compared to corn silage fed controls) For Ruminants Fed Ensiled Beef Cattle Manure

TABLE 51. PERFORMANCE OF RUMINANTS FED ENSILED BEEF CATTLE MANURE AS A FEEDSTUFF COMPARED TO CORN GRAIN FED CONTROLS (kilograms)

Source	Ration	Initial Weight	Final Weight	Weight Gain	Average Daily Gain	Feed Consumption Per Day	Feed Per Kilogram Of Gain	Total Feed Consumed	Total Manure Consumed
Anthony (1969)	Control	250	388.6	138.6	1.10	8.195	7.45	1032.6	-
	20.6% Manure	250	397.4	147.4	1.17	10.858	9.28	1368.1	281.8
	Control	250	371	121	1.10	12.54	11.40	1379.4	-
	11.4% Manure	250	354.5	104.5	0.95	7.98	8.40	877.8	100.1
	22.8% Manure	250	356.7	106.7	0.97	11.271	11.62	1239.8	282.7
	22.8% Manure & G.C.*	250	362.2	112.2	1.02	10.70	10.49	1177.0	268.4
	34.2 % Manure	250	333.6	83.6	0.76	10.26	13.50	1128.6	386.0
Anthony (1971)	Control	285	410	125	1.225	8.991	7.34	917.1	-
	21.1% Manure & CSM †	284	419	135	1.32	11.444	8.67	1167.3	246.3
	22.8 Manure	285	410	125	1.225	11.587	9.46	1181.9	269.5
	Control	337	444	107	0.79	10.649	13.48	1437.6	-
	22.8% Manure	343	475	132	0.97	12.397	12.78	1686.0	384.4
	21.5% Manure & CSM †	346	479	133	0.98	11.715	11.95	1593.2	342.5
	21.9% Manure & Suppl.	342	475	133	0.98	12.250	12.50	1666.0	364.9
	16.4% Manure	346	479	133	0.98	11.133	11.36	1514.1	248.3
	22.8% Manure	342	466	124	0.92	11.513	12.51	1544.3	354.4
	23% Manure	337	477	140	1.04	13.60	13.08	1836.0	422.3
Westing and Brandenberg (1974)	Control	238	443	205	1.11	8.25	7.43	1518.0	-
	14% Manure	238	441	203	1.10	8.66	7.87	1593.4	223.1
Hill et al. (1975)	Control	300	435.5	135.5	1.21	9.39	7.76	1051.7	-
	20% Manure	300	443.4	143.4	1.28	9.60	7.50	1075.2	215.0
	40% Manure	300	447.8	147.8	1.32	9.28	7.03	1039.4	415.8
	60% Manure	300	410.9	110.9	0.99	7.465	7.54	836.1	501.7
Newton et al. (1975)	Control	212	362.1	150.1	1.34	7.571	5.65	848.0	-
	40% Manure	212	354.2	142.2	1.27	11.062	8.71	1239.9	495.6

* G.C. - ground corn

† CSM - cottonseed meal

TABLE 82. PERFORMANCE OF RUMINANTS FED ENSILED BEEF CATTLE MANURE AS A FEEDSTUFF, COMPARED TO CORN GRAIN FED CONTROLS (percent change from the control)

Source	Ration	Initial Weight	Final Weight	Weight Gain and Average Daily Gain	Feed Consumption Per Day and Total Feed Consumed	Feed Consumption Per Kilogram Of Gain
Anthony (1969)	20.6% Manure	0	+2.3	+ 6.3	+32.5	+24.6
	11.4% Manure	0	-4.4	-13.6	-36.4	-26.3
	22.8% Manure	0	-3.9	-11.8	-10.1	+ 1.9
	22.8% Manure & GC*	0	-2.4	- 7.3	-14.7	- 8.0
	34.2% Manure	0	-10.1	-30.9	-18.2	+18.4
Anthony (1971)	21.1% Manure & CSM†	-0.4	+ 2.2	+ 7.9	+27.3	+18.1
	22.8% Manure	0	0	0	+28.9	+28.9
	22.8% Manure	+1.8	+ 7.0	+23.4	+16.4	- 5.2
	21.5% Manure & CSM†	+2.7	+ 7.9	+24.3	+10.0	-11.4
	21.9% Manure	+1.5	+ 7.0	+24.3	+15.0	- 7.3
	16.4% Manure	+2.7	+ 7.9	+24.3	+ 4.5	-15.7
	22.8% Manure	+1.5	+ 5.0	+15.9	+ 8.1	- 7.2
	23% Manure	0	+ 7.4	+30.8	+27.7	- 3.0
Westing and Brandenberg (1974)	14% Manure	0	- 0.5	- 1.0	+ 5.0	+ 5.9
Hill et al. (1975)	20% Manure	0	+ 1.8	+ 5.8	+ 2.2	- 3.3
	40% Manure	0	+ 2.8	+ 9.1	- 1.2	- 9.4
	60% Manure	0	- 5.6	-18.2	-20.5	- 2.8
Newton et al. (1975)	40% Manure	0	- 2.2	- 5.3	+46.1	+54.2

* Ground corn

† Cottonseed meal

group. Therefore, the control group from the third trial was utilized for making comparisons. Four wastelage rations were fed: (1) 40% wastelage (22.8% manure) plus corn; (2) 40% wastelage (21.5% manure) plus corn and soybean meal; (3) 40% wastelage (21.9% manure) plus corn and a commercial supplement; and (4) 30% wastelage (16.4% manure) plus corn and a commercial supplement. The control ration contained ground corn supplemented with urea and was unpalatable, because the steers drooled excessively throughout the study. Therefore, comparisons to this group may be biased. Performance of all wastelage-fed steers was superior to that of controls for all animal performance parameters, except their feed consumption per day increased. In the third trial, a 40% wastelage (22.8% manure) plus ground corn ration and 23% cattle manure plus corn and hay ensiled mixture was fed to steers. Although both groups outperformed the controls with respect to weight gains and feed efficiency, their feed consumption per day increased.

Westing and Brandenberg (1974) studied the effects of substituting composted cattle manure for portions of the corn and alfalfa in a control ration. The performance of the manure-fed steers was not comparable to the control steers because their feed consumption increased and feed efficiency and body weight gains decreased.

Hill et al. (1975) studied the effects of substituting 20, 40 or 60% wet manure ensiled with ground shelled corn, ground hay and a liquid supplement for portions of the corn and ground bermudagrass hay in the control ration. In comparison to the control group, the body weight gains increased for the 20 and 40% manure groups and decreased for the 60% group. Feed consumption per day decreased as the manure content in the ration increased, which indicates a possible palatability problem at high levels.

Newton et al, (1975) studied the effects of substituting 40% cattle manure ensiled with ground corn, bermudagrass pellets and urea for portions of the shelled corn and bermudagrass in the control heifer ration. The performance of the manure-fed heifers was not comparable to the controls. Body weight gains were lower and feed consumption increased.

No correlations were observed between ensiled cattle manure content and any of the animal response parameters when expressed either in kilograms or as a percent change from the control. The lack of any correlation is attributed to variation within and between studies, poor performance of controls and the lack of repeatability.

Economic Value Estimation

The economic estimation of the value of ensiled beef cattle manure as a feedstuff for ruminants (based on feed costs, animal cost and selling price, and economic return), compared to corn silage fed controls, is shown in Tables 83 and 84.

All feed costs significantly increased for the manure-fed steers in the study by Anthony (1968) due to the increased corn content of the feed. Although the animal selling price of the manure-fed steers also increased,

TABLE 83. ECONOMIC ESTIMATE OF THE VALUE OF ENSILED BEEF CATTLE MANURE AS A FEEDSTUFF FOR RUMINANTS COMPARED TO CORN SILAGE FED CONTROLS (dollars)

Source	Ration	Feed Cost Per Tonne	Feed Cost Per Day	Feed Cost Per Kilogram Of Gain	Animal Cost	Total Feed Cost	Animal Selling Price	Economic Return	Gross Value Per Tonne of Manure
Anthony (1968)	Control	40.00	0.3018	0.3316	462.96	42.25	659.56	190.35	-
	22.5% Manure	70.60	0.6269	0.6[illegible]96	462.96	87.77	674.69	123.96	-234.96
Harpster *et al*. (1975)	Control	55.10	0.3510	0.2579	398.15	70.20	817.90	349.55	-
	24% Manure	75.40	0.5323	0.4124	398.15	106.46	796.29	291.68	-170.76
	41.7% Manure	52.40	0.3579	0.2934	398.15	71.58	774.69	304.96	- 78.28
	60% Manure	28.60	0.1796	0.2394	398.15	35.92	629.63	195.56	-204.34
Harpster *et al*. (1978)	Control	73.10	0.5219	0.4744	398.15	95.51	709.87	216.21	-
	24% Manure	75.40	0.6228	0.5821	398.15	113.97	699.07	186.95	- 80.65
	30% Manure	67.60	0.5516	0.5354	398.15	100.94	688.27	189.18	- 60.33
	45% Manure	48.10	0.3733	0.4978	398.15	68.31	609.56	143.10	-114.41

TABLE 84. ECONOMIC ESTIMATE OF THE VALUE OF ENSILED BEEF CATTLE MANURE AS A FEEDSTUFF FOR RUMINANTS COMPARED TO CORN SILAGE FED CONTROLS (percent change from the control)

Source	Ration	Feed Cost Per Tonne	Feed Cost Per Day and Total Feed Costs	Feed Cost Per Kilogram Of Gain	Animal Cost	Animal Selling Price	Economic Return
Anthony (1968)	22.8% Manure	+76.5	+107.7	+92.9	0	+ 2.3	-34.9
Harpster *et al*. (1975)	24% Manure	+36.8	+ 51.7	+59.9	0	- 2.6	-16.6
	41.7% Manure	- 4.9	+ 2.0	+13.8	0	- 5.3	-12.8
	60% Manure	-48.3	- 48.8	- 7.2	0	-23.0	-44.1
Harpster *et al*. (1978)	24% Manure	+ 3.1	+ 19.3	+22.7	0	- 1.5	-13.5
	30% Manure	- 7.5	+ 5.7	+12.9	0	- 3.0	-12.5
	45% Manure	-34.2	- 28.5	+ 4.9	0	-14.1	-33.8

increased feed costs offset any economic benefits and the economic return and the gross value of the manure were negative.

In the studies by Harpster et al. (1975, 1978), all feed costs were higher for the 24% manure ration due to its higher corn content, thus causing the economic return to be negative. Although feed costs per tonne were lower for the 41.7 and 60% manure rations, any economic benefits were negated by the decreased animal selling prices. The economic return was negative for both groups. The gross values of manure were highly negative for all three manure groups, but were not correlated to ration manure content because of differences in ration costs per tonne.

The economic estimation of the value of ensiled beef cattle manure as a feedstuff for ruminants (based on feed costs, animal cost and selling price, and economic return), compared to corn grain fed controls, are presented in Tables 85 and 86.

In the study by Anthony (1969), feed costs per tonne were reduced for the manure rations, and although animal selling prices were generally decreased, they were offset by the feed cost savings and an economic benefit was realized as indicated by the increased economic return. The gross value of the manure in these studies varied widely but average $115 per tonne.

In a second study by Anthony (1971), all feed costs were lower for the manure rations, the animal selling prices were higher, and an economic benefit was realized as indicated by the increased economic returns. The gross value of the manure in these studies was variable and averaged $153 per tonne. The performance of the control group for trials 2 and 3 were reduced because of a palatability problem and therefore the estimated value of the manures may be biased.

All feed costs were reduced for the manure-fed steers in the study by Westing and Brandenberg (1974). The animal selling price was slightly reduced, and thus the increased economic return reflects feed cost savings only. The gross value of the manure was low ($27.25 per tonne) and may be due to the lack of an increase in animal performance and the increased feed consumption by the manure-fed steers.

In the study by Hill et al. (1975), all feed costs decreased in proportion to the manure content in the ration. The economic return increased for all the manure rations. The return for the 20 and 40% manure groups reflect both feed cost savings and increased animal selling prices, but the return for the 60% manure group reflects feed cost savings only. The gross value of the manure varied and averaged $126 per tonne.

The results of Newton et al. (1975) indicated reduced feed costs for the ensiled-cattle manure rations. However, the selling price of the heifers was reduced. The negative economic return reflects reduced animal performance that was not offset by feed cost savings. The gross value of the manure was negative (-$2.38 per tonne) because of reduced animal performance and the significantly increased feed consumption by manure-fed heifers.

TABLE 85. ECONOMIC ESTIMATE OF THE VALUE OF ENSILED BEEF CATTLE MANURE AS A FEEDSTUFF FOR RUMINANTS COMPARED TO CORN GRAIN FED CONTROLS (dollars)

Source	Ration	Feed Cost Per Tonne	Feed Cost Per Day	Feed Cost Per Kilogram Of Gain	Animal Cost	Total Feed Cost	Animal Selling Price	Economic Return	Gross Value Per Tonne of Manure
Anthony (1969)	Control	116.90	0.9580	0.8709	385.80	120.71	599.69	93.18	-
	20.6% Manure	95.20	1.0337	0.8835	385.80	130.25	613.28	97.23	14.37
	Control	107.40	1.3468	1.2244	385.80	148.15	572.53	38.58	-
	11.4% Manure	97.10	0.7749	0.8156	385.80	85.24	547.06	76.02	374.03
	22.8% Manure	87.60	0.9873	1.0179	385.80	108.60	550.46	56.06	61.83
	22.8% Manure & ground corn	87.60	0.9373	0.9189	385.80	103.10	558.95	70.05	117.25
	34.2% Manure	78.20	0.8023	1.0557	385.80	88.25	514.81	40.76	5.65
Anthony (1971)	Control	117.30	1.0546	0.8610	439.81	107.57	632.71	85.33	-
	21.1% Manure *	86.40	0.9888	0.7491	438.27	100.86	646.60	107.47	89.89
	22.8% Manure	76.30	0.8841	0.7218	439.81	90.18	632.71	102.72	64.53
	Control	106.80	1.1373	1.4397	520.06	153.54	685.18	11.58	-
	22.8% Manure	76.30	0.9459	0.9751	529.32	128.64	733.02	75.06	165.14
	21.5% Manure *	83.50	0.9782	0.9978	533.95	133.04	739.19	72.20	176.99
	21.9% Manure	81.00	0.9923	1.0125	527.77	134.95	733.02	70.30	160.92
	16.4% Manure	88.50	0.9853	1.0054	533.95	134.00	739.19	71.24	240.27
	22.8% Manure	76.30	0.8784	0.9545	527.77	118.58	719.13	72.78	172.69
	23 % Manure	76.10	1.0350	0.9954	520.06	139.72	736.11	76.33	153.33
Westing and Brandenberg (1974)	Control	116.80	0.9636	0.8678	367.28	177.30	683.34	138.76	-
	14% Manure	105.70	0.9154	0.8319	367.28	168.43	680.55	144.84	27.25
Hill *et al.* (1975)	Control	104.70	0.9831	0.8125	462.96	110.11	672.06	98.99	-
	20% Manure	83.80	0.8045	0.6285	462.96	90.10	684.25	131.19	149.77
	40% Manure	62.90	0.5837	0.4422	462.96	65.37	691.04	162.71	153.25
	60% Manure	42.00	0.3135	0.3167	462.96	35.11	634.10	136.03	73.73
Newton *et al.* (1975)	Control	113.50	0.8593	0.6413	350.22	96.24	598.19	151.73	-
	40% Manure	68.10	0.7533	0.5932	350.22	84.37	585.14	150.55	-2.38

* plus cottonseed meal

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TABLE 86. ECONOMIC ESTIMATE OF THE VALUE OF ENSILED BEEF CATTLE MANURE AS A FEEDSTUFF FOR RUMINANTS COMPARED TO CORN GRAIN FED CONTROLS (percent change from the control)

Source	Ration	Feed Cost Per Tonne	Feed Cost Per Day and Total Feed Costs	Feed Cost Per Kilogram Of Gain	Animal Cost	Animal Selling Price	Economic Return
Anthony (1969)	20.6% Manure	-18.6	+ 7.9	+ 1.4	0	+ 2.3	+ 4.3
	11.4% Manure	- 9.6	-42.5	-33.4	0	- 4.4	+ 97.0
	22.8% Manure	-18.4	-26.6	-16.9	0	- 3.9	+ 45.3
	22.8% Manure*	-18.4	-30.4	-25.0	0	- 2.4	+ 81.6
	34.2% Manure	-27.2	-40.4	-13.8	0	-10.1	+ 5.7
Anthony (1971)	21.1% Manure†	-26.3	- 6.2	-13.0	-0.4	+ 2.2	+ 25.9
	22.8% Manure	-35.0	-16.2	-16.2	0	0	+ 20.4
	22.8% Manure	-28.6	-16.8	-32.3	+1.8	+ 7.0	+548.2
	21.5% Manure†	-21.8	-14.0	-30.7	+2.7	+ 7.9	+523.5
	21.9% Manure	-24.2	-12.7	-29.7	+1.5	+ 7.0	+507.1
	16.4% Manure	-17.1	-13.3	-30.2	+2.7	+ 7.9	+515.2
	22.8% Manure	-28.6	-22.8	-33.7	+1.5	+ 5.0	+528.5
	23% Manure	-28.7	- 9.0	-30.9	0	+ 7.4	+559.2
Westing and Brandenberg (1974)	14% Manure	- 9.5	- 5.0	- 4.1	0	- 0.4	+ 4.4
Hill et al. (1975)	20% Manure	-20.0	-18.2	-22.6	0	+ 1.8	+ 32.5
	40% Manure	-39.9	-40.6	-45.6	0	+ 2.8	+ 64.4
	60% Manure	-59.9	-68.1	-61.0	0	- 5.6	+ 37.4
Newton et al. (1975)	40% Manure	-40.00	-12.3	- 7.5	0	- 2.2	- 0.8

* plus ground corn

† plus cottonseed meal

There were no correlations between any of the economic parameters and the ensiled manure ration content and no maximum economic level of incorporating ensiled beef cattle manure into ruminant rations could be determined. The average gross value of the manure utilized in all the evaluated studies is $122 per tonne, which suggests that economic incentives and benefits may exist for the utilization of this manure as a feedstuff.

Discussion

Ensiling cattle manure from a feedlot with a roughage source, such as bermudagrass hay, has been suggested as a process of enhancing a low value feedstuff (Anthony, 1966; Harpster et al., 1978; McClure et al., 1973). Cattle readily consume such silages, and the ensiling process tends to inactivate bacterial pathogens (Vetter and Burroughs, 1974; Fontenot and Webb, 1975). Palatability problems have been reported when high levels of ensiled cattle waste are incorporated into steer rations (Harpster et al., 1975, 1978; Hill et al., 1975).

Three studies utilizing ensiled cattle manure as a feedstuff for steers were evaluated and compared to corn silage fed steers. The rations containing 22.8 to 24% ensiled cattle manure had higher corn contents than the rations of the controls. Any increased animal performance therefore might be attributed to the corn and not the manure. The evaluation indicated that steers fed ensiled cattle manure generally had decreased body weight gains, increased feed consumption, and decreased feed efficiency. Statistical evaluation of these results revealed that 16-24% ensiled manure was about the maximum level of incorporation. This level is purely mathematical because no studies have used such a low level.

The economic assessment revealed that feed cost savings per tonne were realized for the ensiled manure rations that had no increased corn content when compared to corn silage fed controls. However, reduced animal performance negated any savings, and no economic benefits were realized. When the corn content in the ensiled manure rations was increased, there were no feed cost savings and no economic benefits were realized. The price of corn silage ($14.88 per tonne) is affected by geographical location. Due to the low value of ensiled cattle waste determined in this evaluation (-$135), the two feedstuffs are not economically comparable, even if corn silage increases in cost by a factor of nine. From an animal response and economic basis, the utilization of ensiled beef cattle manure as a ruminant feedstuff appears to offer no economic incentive when compared to corn silage controls.

Five studies utilizing ensiled beef cattle manure as a feedstuff for steers and heifers were evaluated and compared to corn grain fed control animals. The evaluation was severely confounded by the lack of repeatability within and between studies, abnormal performance by control animals, and the lack of nutritionally balanced studies feeding rations of comparable nutrient composition. In some studies, animal performance was increased, while in others utilizing similar levels of ensiled manure, performance was decreased.

The economic assessment revealed that feed cost savings were realized when ensiled cattle manure was utilized as a feedstuff. The economic assessment did not reveal any maximum levels of incorporation due to variation within and between the studies. However, the average estimated gross value ($122 per tonne) for all the evaluated studies indicates that economic incentives and benefits may exist for the utilization of ensiled cattle wastes to ruminants. The gross value does not reflect any collection, ensiling, incorporation or transportation costs that must be considered before the true value of ensiled cattle waste can be determined.

Ensiled cattle manure is a variable product and economic benefits are difficult to delineate. Further studies are required to delineate maximum and "optimum" levels of incorporation of ensiled cattle manure into ruminant rations.

In summary, the utilization of ensiled beef cattle manure as a feedstuff for ruminants decreased weight gains, increased feed consumption and decreased feed efficiency when compared to corn silage-fed controls. Therefore, animal performance suggests that there are no economic incentives for the utilization of ensiled beef cattle manure as a feedstuff for ruminants.

When the performance of ensiled beef cattle manure is compared to corn grain-fed controls, definite benefits could not be clearly determined due to the lack of repeatability between studies. The economic assessment indicated that economic benefits might be realized; however, additional feeding studies must be conducted to determine the validity of such possible benefits.

SUMMARY OF BEEF CATTLE MANURE FEEDING TRIAL EVALUATIONS

The utilization of beef cattle manure as a feedstuff for ruminants is summarized in Table 87. The incorporation of both as collected and dried cattle manure is unfeasible because of the reduced animal performance of ruminants fed these manures.

The incorporation of ensiled beef cattle manure as a feedstuff for ruminants, when compared to corn silage controls, also appears unfeasible because of reduced animal performance. Body weight gains and feed efficiency are significantly reduced when steers are fed ensiled cattle manure. It also appears uneconomical because any feed cost savings are negated by poor animal performance. The ensiled cattle manure is unable to compete economically with the low cost of corn silage.

In contrast, the incorporation of ensiled beef cattle manure as a feedstuff for steers and heifers, when compared to corn grain-fed control animals, may be nutritionally and economically feasible. Due to the variation in the animal performance evaluation, definite benefits cannot be determined. However, the gross value of ensiled cattle manure indicates it has economic benefits which provide incentives for its utilization as a feedstuff.

TABLE 87. SUMMARY OF THE MAXIMUM ANIMAL RESPONSE AND ECONOMIC LEVELS OF INCORPORATING BEEF CATTLE INTO RUMINANT RATIONS, AND THE ESTIMATED ECONOMIC VALUE OF THE MANURE

Kind of Cattle Waste	Maximum Animal Response Level, % Dry Matter Basis	Maximum Economic Level, % Dry Matter Basis	Estimated Gross Value of the Manure Per Tonne	Level of Manure Incorporation That The Estimated Gross Value Was Based Upon, %
As Collected	0	0	-$ 15	29-40
Dried	0	0	-$256	10-20
Ensiled				
vs corn silage fed controls	16-24	0	-$135	22-60
vs corn grain fed controls	-	-	$122	11-60

SECTION 10

NUTRITIVE AND ECONOMIC VALUE OF PROCESSED ANIMAL MANURES BASED ON THE RESULTS OF FEEDING TRIALS

INTRODUCTION

Sections 7-9 evaluated as collected, dried, composted and ensiled manures as feedstuffs based upon reported feeding trials. This section continues such evaluations by considering the results of feeding trials in which aerobically and anaerobically digested manures and cattle manure screenings have been evaluated. Trials in which the Cereco products have been used as feedstuffs also have been included and evaluated.

The selection criteria and animal performance and economic assessment methodology identified in Section 7 were used to evaluate information in this section.

AEROBICALLY DIGESTED ANIMAL MANURES

The utilization of aerobically digested animal manures as feedstuffs can be divided into three categories: (1) dried settled solids; (2) liquid oxidation ditch mixed liquor (ODML) incorporated into rations; and (3) liquid ODML utilized as a tap water substitute. Due to a lack of data on nutrient characteristics, complete results on animal performance, and economic parameters; the normal evaluation of animal performance and economic assessment could not be conducted. However, each of the three categories will be evaluated utilizing what information has been reported.

Early studies were conducted by Harmon et al. (1969, 1973) utilizing dried swine ODML settled solids as a feedstuff for rats. These studies indicated that the settled solids were of low nutritive value and depressed animal performance. It was concluded that the nutritive portion of ODML was located in the liquid fraction of the ODML, which was substantiated by Chastain et al. (1975). Beef ODML settled solids have been used as a feedstuff for steers (Hegg et al. 1974, 1975). The beef settled solids also adversely affected animal performance. It can be concluded from these studies that ODML settled solids are of low nutritive value.

Harmon et al. (1973) utilized swine ODML as a feedstuff and the feeding trials are summarized in Table G-32. The performance of swine (body weights, feed consumption, and ODML consumption) fed aerobically digested swine manure as a feedstuff, is shown in Tables

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88 and 89. The performance of the liquid fed hogs was enhanced. Although feed consumption per day increased, average daily gains also increased and feed efficiency was improved. All feed costs were reduced for the ODML fed hogs, their animal selling prices were increased, and therefore the economic return for the ODML fed hogs was greatly increased (Tables 90 and 91). The estimated economic value of the ODML averaged $296.22 per tonne, but its actual value will be lower due to capital investments, operating costs, and feed mixing costs.

The utilization of ODML as a substitute for tap water to swine also has been studied by Harmon and Day (1974, 1975) and the feeding trials are summarized in Table G-32. In the first study, the performance of the hogs receiving swine ODML was enhanced (Tables 92 and 93). Average daily gain was greater than for the controls and feed efficiency was improved. In the second study (1975), two groups of hogs received ODML as a water source, but a control group was lacking. Thus, comparisons of performance are not possible. It can be concluded that feed consumption, average daily gain, and feed efficiency were normal. The economic estimate of the value of swine ODML as a substitute for tap water is shown in Tables 94 and 95. All feed costs were reduced for the ODML hogs, the selling price was increased, and the large increase in economic returns reflect both reduced feed costs and increased animal performance. Care must be taken to insure that proper aerobic conditions are maintained because ammonia and nitrates could reach toxic levels and depress the performance of animals receiving ODML as a tap water substitute.

The utilization of ODML as the source of drinking water to laying hens has occurred (Martin et al., 1976 and Martin, 1980). The results of these studies are shown in Table 96. No significant differences were observed in final body weights, mortality, egg weights, or shell strength. Egg production, however, was significantly increased by 2% (P=0.01) in the 1976 study and 2.6% (P=0.01) in the 1980 study. The increased egg production represents an economic incentive for utilizing this method of recycling nutrients. The economic value of the increased egg production was reported to be $24,000 (for a 2% increase) or $31,200 (for a 2.6% increase), for a 100,000 bird operation (Martin, 1980). Although the net economic value would be less due to capital and operating costs associated with the aeration system operation, it appears that the economic incentive would still exist. Care must be taken in the operation of the oxidation ditch because over-aeration has been reported to cause nitrate toxicity and depressed bird performance (Johnson et al., 1977).

In summary, the utilization of ODML as a substitute for tap water to swine and poultry seems to have benefits. Further studies are needed to delineate the nutrient characteristics of ODML, to determine how much microbial enhancement occurs, and to develop the operating procedures necessary to maximize the nutrient composition of ODML.

TABLE 88. PERFORMANCE OF SWINE FED AEROBICALLY DIGESTED SWINE MANURE (ODML) AS A FEEDSTUFF (kilograms)

Source	Ration	Initial Weight	Final Weight	Weight Gain	Average Daily Gain	Feed Consumption Per Day	Feed Per Kilogram Of Gain	Total Feed Consumed	Total ODML Consumed, Dry Matter Basis
Harmon *et al.* (1973)	Control	43	72.12	29.12	0.52	2.09	4.02	117.04	--
	6% ODML	43	74.36	31.36	0.56	2.11	3.77	118.16	7.09
	Control	43	60.92	17.92	0.32	1.79	5.59	100.24	--
	5.7% ODML	43	62.04	19.04	0.34	1.83	5.38	102.48	5.84

TABLE 89. PERFORMANCE OF SWINE FED AEROBICALLY DIGESTED SWINE MANURE (ODML) AS A FEEDSTUFF (PERCENT CHANGE FROM THE CONTROL)

Source	Ration	Initial Weight	Final Weight	Weight Gain and Average Daily Gain	Feed Consumption Per Day and Total Feed Consumed	Feed Consumption Per Kilogram of Gain
Harmon *et al.* (1973)	6% ODML	0	+ 3.1	+ 7.7	+ 1.0	- 6.2
	5.7% ODML	0	+ 1.8	+ 6.2	+ 2.2	- 3.8

TABLE 90. ECONOMIC ESTIMATE OF THE VALUE OF AEROBICALLY DIGESTED SWINE MANURE (ODML) AS A FEEDSTUFF FOR SWINE (DOLLARS)

Source	Ration	Feed Cost Per Tonne	Feed Cost Per Day	Feed Cost Per Kilogram Of Gain	Animal Cost	Total Feed Cost	Animal Selling Price	Economic Return	Gross Value Per Tonne of ODML D.M.
Harmon *et al.* (1973)	Control	127.90	0.2673	0.5142	35.15	14.97	58.83	8.71	--
	6.0% ODML	120.10	0.2534	0.4528	35.15	14.19	60.66	11.32	368.12
	Control	106.60	0.1908	0.5959	35.15	10.69	49.69	3.85	--
	5.7% ODML	100.50	0.1839	0.5407	35.15	10.30	50.61	5.16	224.32

TABLE 91. ECONOMIC ESTIMATE OF THE VALUE OF AEROBICALLY DIGESTED SWINE MANURE (ODML) AS A FEEDSTUFF FOR SWINE (PERCENT OF THE CONTROL)

Source	Ration	Feed Cost Per Tonne	Feed Cost Per Day and Total Feed Costs	Feed Cost Per Kilogram Of Gain	Animal Cost	Animal Selling Price	Economic Return
Harmon *et al.* (1973)	6% ODML	- 6.1	- 5.2	- 11.9	0	+ 3.1	+ 30.0
	5.7% ODML	- 5.7	- 3.6	- 9.3	0	+ 1.9	+ 34.0

TABLE 92. PERFORMANCE OF SWINE RECEIVING AEROBICALLY DIGESTED SWINE MANURE (ODML) AS A SUBSITUTE FOR TAP WATER (KILOGRAMS)

Source	Ration	Initial Weight	Final Weight	Weight Gain	Average Daily Gain	Feed Consumption Per Day	Feed Per Kilogram Of Gain	Total Feed Consumed	Total ODML Consumed, Dry Matter Basis
Harmon and Day (1974)	Control	40	100	60	0.66	2.41	3.65	219.3	--
	5% ODML	40	106.4	66.4	0.73	2.40	3.29	218.4	20.4
Harmon and Day (1975)	2.8% ODML	45	83.1	38.1	0.68	2.43	3.57	136.1	7.4
	2.8% ODML	26	79.9	53.9	0.70	2.18	3.11	167.9	10.1

TABLE 93. PERFORMANCE OF SWINE RECEIVING AEROBICALLY DIGESTED SWINE MANURE (ODML) AS A SUBSTITUTE FOR TAP WATER (PERCENT CHANGE FROM THE CONTROL)

Source	Ration	Initial Weight	Final Weight	Weight Gain and Average Daily Gain	Feed Consumption Per Day and Total Feed Consumed	Feed Consumption Per Kilogram of Gain
Harmon and Day (1974)	5% ODML	0	+ 6.4	+ 10.7	- 0.4	- 9.9

TABLE 94. ECONOMIC ESTIMATE OF THE VALUE OF AEROBICALLY DIGESTED SWINE MANURE (ODML) AS A SUBSTITUTE FOR TAP WATER FOR SWINE (DOLLARS)

Source	Ration	Feed Cost Per Tonne	Feed Cost Per Day	Feed Cost Per Kilogram Of Gain	Animal Cost	Total Feed Cost	Animal Selling Price	Economic Return	Gross Value ODML, Per Tonne Dry Matter
Harmon and Day (1974)	Control	127.90	0.3082	0.4668	32.60	28.05	81.50	20.85	--
	5% ODML	127.90	0.3070	0.4208	32.60	27.93	86.72	26.19	261.76

TABLE 95. ECONOMIC ESTIMATE OF THE VALUE OF AEROBICALLY DIGESTED SWINE MANURE (ODML) AS A SUBSTITUTE FOR TAP WATER FOR SWINE (PERCENT CHANGE FROM THE CONTROL)

Source	Ration	Feed Cost Per Tonne	Feed Cost Per Day and Total Feed Costs	Feed Cost Per Kilogram Of Gain	Animal Cost	Animal Selling Price	Economic Return
Harmon and Day (1974)	5% ODML	0	- 0.4	- 9.9	0	+ 6.4	+ 25.6

TABLE 96. PERFORMANCE OF CAGED LAYING HENS RECEIVING AEROBICALLY DIGESTED LAYING HEN MANURE (ODML) AS A SUBSTITUTE FOR TAP WATER

Source	Group	Number Of Birds	Liquid Consumption (mℓ)	Egg Production (%Hen-day)	Egg Weight (gm)	Shell Strength (Kg)	Final Body Weight (Kg)	Mortality (n)
Martin et al. (1976)	Tap Water	108	226	66.6	54.4	3.12	1.91	11
	ODML	108	273	68.6	54.7	3.14	1.90	11
Martin (1980)	Tap Water	325	283	73.5	57.0	3.12	1.94	20
	ODML	325	311	76.1	57.8	3.14	1.91	23

ANAEROBICALLY DIGESTED ANIMAL MANURES

The utilization of anaerobic digester products (dried cake, wet cake, and digester effluent) as feedstuffs for ruminants has been studied and several digestibility trials have been conducted (Table 97).

The substitution of 5, 10 or 20% dried centrifuge cake for alfalfa in sheep rations resulted in decreased digestibility as the dried cake content increased, decreased feed consumption per day and increased fecal nitrogen (Hashimoto et al., 1978). In a second digestibility trial, substituting 5, 10 or 20% dried cake for a similar percent of all the ingredients in control steer rations also resulted in decreased digestibility and significantly increased fecal nitrogen. In addition, feed consumption per day increased.The authors suggested that a component of the nitrogen in the dried cake was less digestible than the nitrogen in the alfalfa hay and that the relatively ineffective utilization of ash may present a major problem in effectively utilizing dried cake as a feedstuff, particularly when more than one cycle of the refeeding process occurs.

Utilizing wet centrifuge cake, obtained from the Hamilton Standard Mobile Animal Waste Processing System, as a feedstuff for steers has been reviewed by Prior and Hashimoto (1980). The digestibility of the dry and organic matter for the wet cake ration was slightly decreased, nitrogen digestibility was comparable to the controls, and feed consumption per day decreased. The large decrease in feed consumption (21%) suggests a possible palatability problem. Richter (unpublished data, 1979) stated that the wet cake is of low palatability when incorporated at levels above 20% and concluded that it cannot substitute the entire protein supplement in a steer ration although it may replace part of it.

Digestibility studies utilizing digester effluent as a feedstuff for sheep were conducted by Hashimoto et al. (1978) and as a feedstuff for steers by Prior and Hashimoto (1980). The digestibility of the 6.5% effluent sheep ration decreased, fecal nitrogen increased, and feed consumption per day increased (Table 97). Feed consumption per day increased 8.1% when 6.5% effluent was added to the sheep rations, which indicates it may have acted as a diluent. The addition of 6.5% digester effluent to a steer ration similarly decreased dry matter digestibility and increased feed consumption per day 4% when compared to positive controls (Table 97). The authors suggest that a portion of the organic nitrogen in the effluent appeared to be undigestible, and the effluent may have adversely affected the rumen microbial metabolism, or perhaps the rate of turnover of rumen contents. However, later studies have shown that the rate of turnover of the rumen contents was not significantly different (Prior et al., 1980).

The results of the digestibility studies indicate that digester products contain organic nitrogen that appears to be indigestible by ruminants and that palatability problems may occur when these products are utilized at high levels as ruminant feedstuffs. Animals fed these products did not perform as well as controls, and the products tended to function as fillers or diluents.

TABLE 97. PERFORMANCE OF RUMINANTS ON DIGESTIBILITY TRIALS FED ANAEROBICALLY DIGESTED ANIMAL MANURES AS A FEEDSTUFF

Feedstuff	Source	% in Ration, Dry Matter	Percent Apparent Digestibility					Kg Feed Consumed Per Day	Feedstuff Replaced or Eliminated in Ration
			Dry Matter	Organic Matter	Ash	Gross Energy	Nitrogen		
Dried Cake (to sheep)	Hashimoto et al. (1978)	0	72.5	73.5	59.5	70.2	58.5	1.027	Alfalfa Hay
		5	71.6	73.5	46.3	70.0	55.1	0.970	
		10	72.2	75.2	40.0	71.4	63.9	0.866	
		20	68.0	71.5	28.4	68.1	51.4	0.947	
Dried Cake (to steers)	Hashimoto et al. (1978)	0	77.2	78.5	51.2	75.4	63.4	4.85	Hay, Corn, Soybean Meal & Limestone
		5	71.1	72.7	31.5	70.1	60.3	5.37	
		10	72.1	73.7	50.6	70.8	61.8	4.91	
		20	62.9	65.4	28.0	63.8	54.2	5.36	
Wet Cake (to steers)	Richter (1979)	0	69.9	69.9	-	-	52.5	11.7	Cottonseed Meal
		30	67.1	67.9	-	-	52.6	9.2	
Effluent (to sheep)	Hashimoto et al. (1978)	0	81.4	82.8	66.2	81.3	72.6	0.777	Soybean Meal
		6.5	75.4	77.1	39.8	74.4	58.8	0.840	
Effluent (to steers)	Prior and Hashimoto (1980)	0	76.1	-	-	-	61.5	5.291	Soybean Meal
		6.5	73.9	-	-	-	61.5	5.495	
		Neg. 0	77.6	-	-	-	70.5	5.404	

Two feeding studies have been conducted utilizing digester products as a feedstuff for steers (Table G-33). The complete nutrient composition of the rations utilized in these studies were not reported and cannot be calculated because of the lack of information pertaining to the nutrient composition of the digester products.

Animal Performance Evaluation

The performance of ruminants (body weights, feed consumption, and digestor product consumption) fed anaerobically digested animal manures as a feedstuff is presented in Tables 98 and 99.

The effects of substituting 18% (as-fed) wet centrifuged digester effluent cake for the cottonseed meal, straw and limestone in the control finishing steer ration were studied by Burford and Varani (1978). Body weight gains and feed consumption per day were significantly lower, and feed consumption per kilogram of gain was higher for the wet cake-fed steers. The decreased daily feed consumption indicates that a possible palatability problem may have occurred for the wet cake ration, similar to that observed in the digestibility study.

The effects of substituting 6.45% (dry matter basis) digester effluent for the soybean meal in a positive control ration (containing protein supplement) were studied by Prior and Hashimoto (1980). The effects were also compared to a negative control group receiving no protein supplement. Body weight gains were significantly reduced, feed consumption per day increased, and feed efficiency significantly decreased for the effluent-fed steers. The poorer animal performance of the effluent-fed steers did not appear as great when compared to the negative control group. However, the steers that were not fed a protein supplement outperformed the effluent-fed steers.

The evaluation of animal performance of both the wet digester centrifuged cake and the digester effluent as a feedstuff for finishing steers indicated that both products have a negative effect upon animal performance. Body weight gains and feed efficiency were significantly depressed. No benefits appear to exist when anaerobic digester products are used as feedstuffs.

Economic Value Estimation

The economic estimation of the value of anaerobically digested animal manures as a feedstuff for ruminants (based on feed costs, animal cost and selling price, and economic return) is shown in Tables 100 and 101.

All feed costs were lower for the steers fed the wet cake in the study by Burford and Varani (1978). Although a feed costs savings was realized, it was negated by a lower animal selling price, and the economic return was negative. The estimated value of the wet cake was negative (-$102.39 per tonne) due to the reduced animal performance.

In the study by Prior and Hashimoto (1980), feed costs per tonne and per day were reduced for the effluent-fed steers. However, feed efficiency

TABLE 98. PERFORMANCE OF RUMINANTS FED ANAEROBICALLY DIGESTED ANIMAL MANURES AS A FEEDSTUFF (kilograms)

Source	Initial Weight	Final Weight	Total Weight Gain	Average Daily Gain	Feed Consumption Per Day*	Feed Per Kilogram Of Gain*	Total Feed Consumed*	Total Digester Product Consumed
Burford and Varani (1978)								
Control	294.8	423.4	128.6	1.67	14.225	8.50	1095.3	-
18% Wet Cake	294.8	398.7	103.9	1.35	11.916	8.85	917.5	165.15 (77.07)†
Prior and Hashimoto (1980)								
Positive Control	293.1	459.4	166.3	0.99	5.291	5.344	888.9	-
6.45% Effluent	285.9	418.6	132.7	0.79	5.495	6.956	923.2	59.55
Negative Control	294.2	450.4	156.2	0.93	5.404	5.811	907.9	-

* "as fed" basis

† Dry matter basis

TABLE 99. PERFORMANCE OF RUMINANTS FED ANAEROBICALLY DIGESTED ANIMAL MANURES AS A FEEDSTUFF (percent change from the control)

Source	Initial Weight	Final Weight	Total Weight Gain and Average Daily Gain	Feed Consumption Per Day and Total Feed Consumed	Feed Per Kilogram Of Gain
Burford and Varani (1978)					
18% Wet Cake	0	-5.8	-19.2	-16.2	+4.1
Prior and Hashimoto (1980)					
6.45 Effluent					
vs Positive Control	-2.5	-8.9	-20.2	+ 3.9	+30.2
vs Negative Control	-2.8	-7.1	-15.0	+ 1.7	+19.7

TABLE 100. ECONOMIC ESTIMATE OF THE VALUE OF ANAEROBICALLY STABILIZED ANIMAL MANURES AS A FEEDSTUFF FOR RUMINANTS (dollars)

Source	Feed Cost Per Tonne	Feed Cost Per Day	Feed Cost Per Kilogram Of Gain	Total Feed Cost	Animal Cost	Animal Selling Price	Economic Return	Gross Value Per Tonne of Digester Product
Burford and Varani (1978)								
Control	85.80	1.2205	0.7293	93.98	454.94	653.39	104.47	-
18% Wet Cake	79.40	0.9461	0.7027	72.85	454.94	615.35	87.56	-102.39
Prior and Hashimoto (1980)								
Positive Control	105.60	0.5587	0.5643	93.96	452.31	708.95	162.78	-
6.45% Effluent	92.18	0.5065	0.6412	85.09	441.20	645.98	119.69	-723.59*
Negative Control	99.00	0.5350	0.5753	89.88	454.01	695.06	151.17	-528.63†

*Gross value compared to positive control group
†Gross value compared to negative control group

TABLE 101. ECONOMIC ESTIMATE OF THE VALUE OF ANAEROBICALLY STABILIZED ANIMAL MANURES AS A FEEDSTUFF FOR RUMINANTS (percent change from the control)

Source	Feed Cost Per Tonne	Feed Cost Per Day and Total Feed Cost	Feed Cost Per Kilogram Of Gain	Animal Cost	Animal Selling Price	Economic Return
Burford and Varani (1978)						
18% Wet Cake	- 7.5	-22.5	- 3.6	0	-5.8	-16.2
Prior and Hashimoto (1980)						
6.45% Effluent						
vs Positive Control	-12.7	- 9.3	+13.6	-2.5	-8.9	-26.5
vs Negative Control	- 6.9	- 5.3	+11.5	-2.8	-7.1	-20.8

costs increased due to the poor feed conversion by the effluent fed steers. Due to the decreased body weight gains, the animal selling prices were reduced, significantly reducing the economic return. The estimated gross value of the effluent was -$723.59 per tonne when compared to the positive control group and -$528.63 per tonne when compared to the negative control group. These large negative values are attributed to the increased feed efficiency costs and the decreased animal selling prices.

The economic assessment of the utilization of the centrifuged digester cake and the digester effluent as feedstuffs for finishing steers indicated that both products have a negative economic value. Feed efficiency decreased significantly and animal selling prices decreased; thus no economic benefits are realized for the utilization of anaerobic digester effluent products as a feedstuff.

Discussion

The evaluation of utilizing anaerobic digester products (dried cake, wet cake or effluent) as a feedstuff for ruminants indicated they are of limited value based upon the poor performance of animals receiving them in a ration. In both the digestibility studies and the feeding trials, animals fed digester products did not perform as well as control animals, even negative control animals. The economic assessment indicated that digester products are not an economic feedstuff for ruminants. There appear to be no benefits or incentives for the utilization of digester products as feedstuffs.

BEEF CATTLE AND DAIRY COW MANURE SCREENINGS

The utilization of manure screenings as a feedstuff for ruminants has been studied to a limited extent and a few studies have reported the results from feeding trials. Because most of these reports were published as abstracts, accurate, descriptive information pertaining to experimental design, ration characteristics, and complete animal performance were not reported. The evaluation of animal performance and the economic assessment of these studies could not be as thorough as previous evaluations due to the lack of reported animal response results.

Two studies utilizing beef cattle manure screenings as a feedstuff for steers and brood cows are summarized in Table G-34. The performance of ruminants (body weight gains, feed consumption, and screening composition) fed beef cattle manure screenings as a feedstuff is presented in Tables 102 and 103.

In the study by Richter and Shirley (1977), only body weight gain and average daily gain were reported for the control and steers fed screenings. All steers fed screenings significantly increased their body weight gains, with the largest increase occurring at 40% screenings. Although feed consumption data were not reported, it was noted that as the screening content increased, the ration digestibility decreased. The authors reported that utilizing screenings as a feedstuff resulted in significant concentrate savings per kilogram of gain. This statement cannot be evaluated due to the lack of feed consumption data.

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TABLE 102. PERFORMANCE OF RUMINANTS FED BEEF CATTLE MANURE SCREENINGS AS A FEEDSTUFF (kilograms)

Source	Ration	Initial Weight	Final Weight	Weight Gain	Average Daily Gain	Feed Consumption Per Day	Feed Consumption Per Kilogram Of Gain	Total Feed Consumption	Total Screenings Consumed Dry Matter Basis
Richter and Shirley (1977)	Control	-	-	136.4	1.10	-	-	-	-
	20% Screenings	-	-	189.7	1.53	-	-	-	-
	40% Screenings	-	-	195.9	1.58	-	-	-	-
	60% Screenings	-	-	184.8	1.49	-	-	-	-
Schake *et al.* (1977)	Control	394.5	474.1	79.6	1.35	10.6	7.9	625.4	-
	39% (18%)*	399.1	462.8	63.7	1.08	11.1	10.3	654.9	117.9
	60.5% (35%)*	390.9	457.0	66.1	1.12	9.0	8.1	531.0	185.8
	74.5% (50%)*	398.0	462.9	64.9	1.10	9.2	8.4	542.8	271.4
	74.5% (50%)*	392.6	420.5	27.9	0.93	8.7	9.4	261.0(513.3)†	130.5(256.6)†
	86.5% (68.6%)*	420.5	429.2	8.7	0.38	8.2	27.3	237.8(483.8)†	163.1(331.9)†

* Numbers in parenthesis represent dry matter values
† Calculated consumption for a 59-day trial

TABLE 103. PERFORMANCE OF RUMINANTS FED BEEF CATTLE MANURE SCREENINGS AS A FEEDSTUFF (percent change from the control)

Source	Ration	Initial Weight	Final Weight	Total Weight Gain and Average Daily Gain	Feed Consumption Per Day and Total Feed Consumed	Feed Consumption Per Kilogram Of Gain
Richter and Shirley (1977)	20% Screenings	-	-	+39.1	-	-
	40% Screenings	-	-	+43.6	-	-
	60% Screenings	-	-	+35.5	-	-
Schake *et al.* (1977)	39% Screenings	+1.2	- 2.4	-20.0	+ 4.7	+ 30.4
	60.5% Screenings	-0.9	- 3.6	-17.0	-15.1	+ 2.5
	74.5% Screenings	+0.9	- 2.4	-18.5	-13.2	+ 6.3
	74.5% Screenings	+0.5	-11.3	-31.1	-24.5	+ 19.0
	86.5% Screenings	+6.6	- 9.5	-71.9	-22.6	+245.6

Schake et al. (1977) fed beef cattle screenings to brood cows at various levels ranging from 39 to 86.5% (18 to 68.6%, dry matter basis). The screenings eliminated the sudangrass hay and reduced the sorghum grain and molasses in the control ration. All body weight parameters and feed consumption parameters decreased for the cows fed the screenings. The results suggest that beef cattle screenings can decrease the performance of brood cows.

Two studies utilizing dairy cow manure screenings as a feedstuff for steers and heifers are summarized in Table G-34. The performance of steers and heifers (body weight gains, feed consumption, and screening consumption) fed dairy cow manure screenings as a feedstuff are shown in Tables 104 and 105.

In the first of two trials, Johnson et al. (1975b) fed two screening rations to steers. The first ration contained 33% screenings, 27% corn silage, and 40% concentrates, and the second ration contained 45% screenings, 5% corn silage and 50% concentrates. The performance of steers fed 45% screenings was significantly reduced. Body weight gains were much lower and feed efficiency was extremely poor when compared to the steers fed 33% screenings. Due to the lack of a control group, the performance of the screening fed groups cannot be evaluated. In the second trial, steers were fed a ration containing 30% screenings, and 70% concentrates, and their performance was compared to control steers fed a ration containing 58% corn silage and 42% concentrates. Body weight gains and feed consumption per day were slightly reduced, but feed efficiency was improved for the steers fed the screenings. The results indicate: (1) utilizing approximately 30% screenings in a steer ration may not significantly decrease animal performance and feed efficiency may be improved, and (2) higher levels of screenings may have a negative effect on animal performance.

Olivera et al. (1977) fed heifers a ration containing 50% ensiled screenings plus alfalfa hay and concentrates, and compared their performance to heifers on pasture, supplemented with corn silage and concentrates. Body weight gains were slightly decreased for the heifers fed the screenings but there were no adverse effects related to the dates of first heat or final service. In a second trial, two groups of steers were fed rations containing either 30% fresh or ensiled screenings, 20% corn silage and 50% concentrates. There were no significant differences for weight gains or feed consumption for either group of steers fed the screenings. These results suggest that ensiling dairy manure screenings does not enhance its nutritive value, which is in agreement with the study by Mercio and Johnson (1978).

The evaluation of the practice of utilizing manure screenings as a feedstuff for ruminants indicates that the screenings contain nutritive value that can be utilized for maintenance and/or growth. This area of refeeding requires further sutdy to identify the nutrient composition of screenings, the influence of the ration on screening characteristics, the digestibility of screenings and maximum and "optimum" levels of utilization.

The economic evaluation of the use of screenings as a feedstuff is confounded by the lack of animal performance results. Ration costs and feed

TABLE 104. PERFORMANCE OF RUMINANTS FED DAIRY COW MANURE SCREENINGS AS A FEEDSTUFF (kilograms)

Source	Ration	Initial Weight	Final Weight	Weight Gain	Average Daily Gain	Feed Consumption Per Day	Feed Consumption Per Kilogram Of Gain	Total Feed Consumption	Total Screenings Consumed
Johnson et al. (1975b)	33% Screenings	-	-	25.2	0.9	4.8	5.33	134.4	44.4
	45% Screenings	-	-	11.2	0.4	4.4	11.00	123.2	55.4
	Control	-	-	66.7	0.89	6.4	7.25	480	-
	30% Screenings	-	-	63.7	0.85	6.0	7.03	450	135
Olivera et al. (1977)	Control	188	271	83.0	0.48	-	-	-	-
	50% ensiled	189	264	75.0	0.42	-	-	-	-
	30%	212	303	91.0	0.89	6.6	7.4	673.2	202.0
	30% ensiled	208	297	89.0	0.87	6.8	7.8	693.6	208.1

TABLE 105. PERFORMANCE OF RUMINANTS FED DAIRY COW MANURE SCREENINGS AS A FEEDSTUFF (percent change from the control)

Source	Ration	Initial Weight	Final Weight	Total Weight Gain and Average Daily Gain	Feed Consumption Per Day and Total Feed Consumed	Feed Consumption Per Kilogram Of Gain
Johnson et al. (1975b)	30% Screenings	-	-	-4.5	-6.2	-3.0
Olivera et al. (1977)	50% ensiled	+0.5	-2.6	-9.6	-	-

consumption data. Therefore, an estimated economic value cannot be assigned to screenings until further studies are conducted and the results reported in detail. The screenings have an apparent value as a feedstuff, as indicated by the feeding trials, and may also have value as a source of bedding and as a product for horticultural use.

CERECO PRODUCTS AS FEEDSTUFFS

The utilization of Cereco products (CI - high fiber silage and CII - dried protein product) as feedstuffs has been investigated by a few experimenters. A digestibility trial was conducted by Ward et al. (1975) utilizating both Cereco products and the results are presented in Tables 106 and 107. The control steers were fed a ration of corn silage. Both groups received a protein-vitamin supplement. Average daily feed consumption was higher for the control steers than those fed CI (17.0 versus 11.5 kg, dry matter basis). The digestibility of the nutrients in the CI product were similar to the digestibility of corn silage.

The same steers used in the CI digestibility trial were utilized in the CII digestion trial. The control steers received a ration of 41.5% corn silage, 48.9% cracked corn and 6% soybean meal. The other steers were fed a ration of 42.6% corn silage, 46.1% cracked corn and 11.3% CII product. Average daily feed consumption was higher for the control steers than those fed CII (7.7 versus 7.2 kg). The digestibility of the CII is slightly lower than the digestibility of soybean meal, and the CII fed steers had a lower nitrogen balance and less nitrogen retained than the controls (Table 107). Fecal samples collected from both groups of steers were similar in composition with the exceptions of an increased ash and crude fiber content for the CII-fed steers. The increased fecal ash content may pose a problem in a continuous recycled system unless a part of the ash is removed prior to refeeding manure from the CII-fed steers.

TABLE 106. PERFORMANCE OF STEERS, ON A DIGESTIBILITY TRIAL, FED CERECO HIGH FIBER SILAGE (CI) AS A FEEDSTUFF

	% Digestibility	
Nutrient	High Fiber Silage (CI)	Corn Silage
Protein	55.2	51.0
Crude Fiber	65.3	66.9
Ether Extract	90.6	84.2
NFE	67.1	71.5
Organic Matter	65.6	68.5

TABLE 107. PERFORMANCE OF STEERS, ON A DIGESTIBILITY TRIAL, FED CERECO DRIED PROTEIN PRODUCT (CII) AS A FEEDSTUFF

Nutrient	Dried Protein Product (CII)	Soybean Meal
	% Digestibility	
Dry Matter	65	72.9
Organic Matter	68.6	74.5
Protein	50	60.9
	% Retained	
Nitrogen	16.2	25.3
Digestible Nitrogen	31.8	41.5
Nitrogen Balance (g/day)	21.2	39.0

Two other studies utilizing Cereco products as a feedstuff for steers have been reported and are summarized in Table G-35. The reported composition of the rations utilized in these two studies is presented in Table G-36.

Animal Performance Evaluation

The performance of ruminants (body weight gains, feed consumption, and Cereco product consumption) fed Cereco CI and CII products as a feedstuff is presented in Tables 108 and 109.

Lambeth *et al*. (1974) replaced portions of the corn silage and the protein supplement in the control rations with 8% CII or 4% CII plus urea. A negative control group, containing no supplemental protein, was also used. The negative control group outperformed the positive control group. When compared to the positive control group, the body weight gains and feed consumption per day of the steers fed 8% CII were slightly decreased and the feed efficiency was similar. The steers fed 4% CII plus urea gained more weight, feed consumption per day was comparable to controls, and feed efficiency was improved. When compared to the negative control group, body weight gains, feed consumption per day and feed efficiency of the steers fed 8% CII were reduced. Body weight gains for the steers fed 4% CII plus urea were slightly less than the negative controls, and feed consumption per day decreased and feed efficiency was improved. The animals utilized in this study were mature steers whose protein requirements were low. The authors suggested that the 8% CII ration was too high in protein, causing the feed consumption per day to decrease.

In the second study, the influence of substituting 8.3% CI or 3.9% CII for the corn silage or corn in the control ration of steers was investigated

TABLE 108. PERFORMANCE OF RUMINANTS FED CERECO PRODUCTS AS A FEEDSTUFF (kilograms)

Source	Initial Body Weight	Final Body Weight	Body Weight Gain	Average Daily Gain	Feed Consumption Per Day	Feed Consumption Per kg Gain	Total Feed Consumed	Total Product Consumed
Lambeth et al. (1974)								
Control	377.8	508.5	130.7	1.436	11.458	7.98	1042.7	-
8% CII	368.3	497.6	129.3	1.419	11.299	7.96	1028.2	82.3
4% CII & Urea	375.4	512.5	137.1	1.506	11.553	7.67	1051.3	42.1
Negative Control	375.8	513.7	137.9	1.514	11.871	7.84	1080.3	-
Lambeth (1975)								
Control	356.1	547.3	191.2	1.416	9.380	6.624	1266.3	-
8.3% CI	351.5	546.4	194.9	1.444	9.552	6.615	1289.5	107.0
3.9% CII	356.1	540.6	184.5	1.367	9.125	6.675	1231.9	48.0

TABLE 109. PERFORMANCE OF RUMINANTS FED CERECO PRODUCTS AS A FEEDSTUFF (percent change from the control)

Source	Initial Body Weight	Final Body Weight	Weight Gain and Average Daily Gain	Feed Per Day and Total Feed Consumed	Feed Consumption per kg Gain
Lambeth et al. (1974)					
vs Positive Control					
8% CII	-2.4	-2.1	-1.1	-1.4	-0.2
4% CII & Urea	-0.6	+0.8	+4.9	+0.8	-3.9
vs Negative Control					
8% CII	-2.0	-3.1	-6.2	-4.8	+1.5
4% CII & Urea	-0.1	-0.2	-0.6	-2.7	-2.2
Lambeth (1975)					
8.3% CI	-1.3	-0.2	+1.9	+1.8	-0.1
3.9% CII	0	-1.2	-3.5	-2.7	+0.8

by Lambeth (1975). Body weight gains were slightly increased for the CI steers, but decreased for the CII steers. Feed consumption per day and feed efficiency for the CI group was similarly increased, but decreased for the CII group.

The animal response evaluation indicated that the CI product is a good substitute for corn silage and will result in comparable or slightly improved animal performance. When the CII product was substituted for corn or a commercial protein supplement, animal performance was not comparable to control steers.

Economic Value Estimation

The economic estimation of the value of Cereco products CI and CII as a feedstuff for ruminants (based on feed costs, animal cost and selling price, and economic returns) are shown in Tables 110 and 111.

All feed costs were reduced for both groups of CII-fed steers in the study by Lambeth et al. (1974). Due to differences in body weight gains, the selling price of 8% CII-fed steers was reduced, while the selling price of the 4% CII plus urea steers was slightly increased. The increased economic return for the 8% CII group reflects feed cost savings only, while the increased economic return for the 4% CII group reflects both feed cost savings and improved animal performance.

The calculated gross value of the CII product utilized in the 8% ration was lower than the value of the CII in the 4% ration. This difference is attributed to the improved animal performance by the 4% steers. If the economic parameters are compared to the negative control steers, feed cost savings are still realized, although they are less, and the animal selling prices for both groups of CII fed steers are decreased. The economic return of the 8% CII group is negative because the feed cost savings are negated by the decreased animal performance and thus the gross value of the CII was negative. The economic return of the 4% CII group is slightly increased because the feed cost savings are able to offset the slightly decreased animal performance and thus the gross value of the CII is positive.

In the second study by Lambeth (1975), all feed costs increased for the CI-fed steers, because the corn content of their ration increased and the resultant ration cost more than the control ration. The animal selling price of the CI-fed steers was comparable to the control group. However, economic return was decreased due to the increased feed costs that were not offset by improved animal performance. The calculated gross value of the CI product was negative (-$5.51 per tonne). All feed costs were reduced for the CII-fed steers, but animal selling price was slightly decreased by lower performance. The calculated gross value of the CII product therefore was low ($19.98 per tonne). Lambeth (1975) utilizing least-cost computer ration formulation, derived the values of $80 per ton for the CI product and $50 per ton for the CII product, with their nutrient values being equal to conventional feedstuffs. However, on the basis of animal performance, the Cereco products are worth less than the noted $80 and $50 per ton.

TABLE 110. ECONOMIC ESTIMATE OF THE VALUE OF CERECO PRODUCTS AS A FEEDSTUFF FOR RUMINANTS (dollars)

Source	Feed Cost Per Tonne	Feed Cost Per Day	Feed Cost Per Kg Gain	Total Feed Cost	Animal Cost	Animal Selling Price	Economic Return	Gross Value Per Tonne of Cereco Product
Lambeth et al. (1974)								
Control	99.32	1.1380	0.7926	103.56	583.02	784.72	98.14	-
8% CII	86.77	0.9804	0.6907	89.22	568.36	767.90	110.32	148.00 (-53.95)*
4% CII & Urea	90.02	1.0400	0.6905	94.64	579.32	790.89	116.93	446.32 (51.54)*
Negative Control	90.77	1.0775	0.7116	98.05	579.93	792.74	114.76	-
Lambeth (1975)								
Control	96.50	0.9056	0.6392	122.26	549.53	844.59	172.80	-
8.3% CI	99.70	0.9523	0.6595	128.56	542.43	843.20	172.21	-5.51
3.9% CII	90.07	0.8219	0.6012	110.96	549.53	834.25	173.76	19.98

* Gross value compared to negative control

TABLE 111. ECONOMIC ESTIMATE OF THE VALUE OF CERECO PRODUCTS AS A FEEDSTUFF FOR RUMINANTS (percent change from the control)

Source	Feed Cost Per Tonne	Feed Cost Per Day and Total Feed Cost	Feed Cost Per Kg Gain	Animal Cost	Animal Selling Price	Economic Return
Lambeth *et al.* (1974)						
vs Positive Control						
8% CII	-12.6	-13.5	-12.9	-2.5	-2.1	+12.4
4% CII & Urea	- 9.4	- 4.0	-12.9	-0.6	+0.8	+19.1
vs Negative Control						
8% CII	- 4.4	- 9.0	- 2.9	-2.0	-3.1	- 3.9
4% CII & urea	- 0.8	- 3.5	- 3.0	-0.1	-0.2	+ 1.9
Lambeth (1975)						
8.3% CI	+ 3.3	+ 5.2	+ 3.2	-1.3	-0.2	- 0.3
3.9% CII	- 6.7	- 9.2	- 5.9	0	-1.2	+ 0.6

The economic assessment revealed that the CI product cannot be economically utilized as a corn-silage substitute if the ground corn content in the ration is increased. The evaluation of the CII product is confusing because of differences in animal performance. Further studies are required to determine its economic value.

Discussion

The utilization of CI as a substitute for corn silage in steer rations is a nutritionally feasible practice on the basis of results of reported digestibility and feeding trials. However, economically CI may not be an appropriate substitute for corn silage when the corn content in the ration is increased. Further studies are required utilizing CI as a direct substitute for corn silage to evaluate its economic value. The economic value of CI has been estimated to range from $73 (Seckler and Ward, 1974) to $88 per tonne (Lambeth, 1975). It must be emphasized that these values reflect nutrient value and not animal performance.

The CII product has been suggested to be comparable to typical protein feedstuffs in its nutritive value (Lambeth, 1975). However, the digestibility and feeding trials indicated that CII cannot be substituted for typical protein feedstuffs on a 1:1 basis without adversely affecting animal performance. As indicated by the estimation of economic value, the value of CII is variable and ranges from -$53.95 to $446.32 but its true economic value cannot be determined because of the variation in animal response.

The greatest economic value of CII may be realized when utilized as a feedstuff for monogastrics (Lambeth, 1975). The utilization of CII as a feedstuff in broiler rations has been reported by Ward _et al_. (1975) and Kienholz _et al_. (1975). Ward _et al_. (1975) concluded that 5% CII-stimulated broiler growth, but 10 and 15% depressed growth rate. Kienholz _et al_. (1975) calculated the value of CII as a replacement for typical feedstuffs. At 1979 prices the value is $100.20 per tonne.

The utilization of CII as a feedstuff in laying hen diets has been reported by Ward _et al_. (1975). The authors concluded that 30% CII could be incorporated into laying hen diets without a decrease in egg production. Feed efficiency of the De Kalb birds decreased by 3% and by 14% for the Hy-Line birds. The authors calculated the replacement value for the CII in the laying diets to be $165.37 per tonne (1974 prices).

Production costs of the Cereco process have been reported to be $65 per tonne (Seckler and Ward, 1974). Adjusting this for inflation (Delury, 1978), the cost is approximately $85 per tonne (1978 prices). Due to the high production costs, the Ceres Ecology Corporation discontinued the process in 1977, although the products are still being produced in France (P. Oriot, personal communication). Recently a pilot study was conducted in California utilizing a new energy-saving process to produce Cereco products from cattle, swine and poultry wastes. Results are unavailable at this time. It can be concluded that Cereco process products have nutritive value, although their economic value cannot be determined at this time.

SUMMARY OF PROCESSED MANURES

The utilization of processed animal manures as a feedstuff and as a tap water substitute for ruminants, swine, and laying hens is summarized in Table 112. The use of aerobically digested swine and laying hen manures as a feedstuff or as a source of drinking water may result in animal performance that is comparable to or better than control animals receiving tap water, and economic benefits might be realized. The utilization of anaerobically digested animal manures as a feedstuff is inappropriate due to poor animal performance. The use of beef cattle and dairy cow manure screenings as a ruminant feedstuff appears to be a sound nutritional practice; however, further studies are required to clearly determine its nutritional and economic values. The Cereco products (CI and CII) have feedstuff value as substitutes for corn silage and protein supplements, but their estimated economic value could not be clearly determined due to variation in animal response.

TABLE 112. SUMMARY OF ANIMAL RESPONSE AND ECONOMIC LEVELS OF UTILIZING PROCESSED ANIMAL MANURES AS A FEEDSTUFF AND AS A TAP WATER SUBSTITUTE FOR RUMINANTS, SWINE AND LAYING HENS AND THEIR ESTIMATED ECONOMIC VALUE

Kind of Processed Manure	Maximum Animal Response Level, (% Dry Matter Basis)	Maximum Economic Level (% Dry Matter Basis)	Estimated Gross Value of Processed Manure Per Tonne Dry Matter (dollars)	Level of Waste Incorporation That The Estimated Gross Value Was Based Upon (%)
Aerobic Digestion				
Swine ODML (in feed)	*	*	296†	5.7 to 6
Swine ODML (as water source)	*	*	262‡	4.7 to 5.3
Laying Hen ODML (as water source)	*	*	273§	1.4
Anaerobic Digestion				
Wet Cake	*	0	-102#	18
Effluent	0	0	-626#	6.45
Manure Screenings				
Beef Cattle	*	*	*	*
Dairy Cow	*	*	*	*
Cereco Products				
CI	*	*	- 6**	8.3
CII	*	*	122**	3.9 to 8.0

* Cannot be determined from existing data

† See Table 90

‡ See Table 94

§ Value based upon 0.275L ODML consumed per hen-day; ODML at 1.4% dry matter; 2.3% increased egg production; egg value at $0.55/dozen;

Calculations:
1- 0.275L ODML x 1.4% DM = 0.00385 kg DM ODML/hen-day
2- 2.3% increased eggs x $0.55/12 = $0.00105
3- 0.00385 kg DM ODML = $0.00105
4- 1000 kg DM ODML = $272.73

# See Table 100

** See Table 110

SECTION 11

SUMMARY

The overall objective of this study was to characterize the value of animal manures as feedstuffs. This was done by comparing the nutrient composition of animal manures to conventional feedstuffs, by evaluating the animal performance resulting from feeding trials, and by preparing an economic assessment.

The nutrient evaluation of animal manures indicated that, generally, they are more comparable to corn silage and typical forages (alfalfa, timothy and bermudagrass hay) for ruminants than to energy or protein feedstuffs and are a source of amino acids and minerals for laying hens. The estimated economic value of these manures, based upon their nutrient content, was $58 per tonne when used to replace corn silage and $80 per tonne when used to replace forages in ruminant rations and $117 per tonne when DPW is used to replace a portion of the cost of meat and bone meal in laying hen diets (Section 5).

Evaluation of animal performance resulting from feeding trials indicated that animal manures have nutritive value as a feedstuff; however, the method used to prepare manures as feed constituents (drying, composting, ensiling, etc.) influences their value. The maximum and "optimum" levels of incorporating animal manures into laying hen diets and ruminant rations, on the basis of animal performance, are summarized in Table 113. Generally, the "optimum" level of incorporating animal manures into diets is less than 20%. Broiler litter, however, is an exception and can be incorporated at higher levels without adversely affecting animal performance.

The economic assessment evaluation of utilizing DPW as a feedstuff is summarized in Table 114. The "optimum" economic level of incorporation is 5 to 12.5% and the maximum economic level is 5 to 35%. The estimated gross value of DPW as a substitute for meat and bone meal or silage and forages, when incorporated at the "optimum" level, exceeds its fertilizer value. However, when incorporated at the maximum level the estimated gross value of DPW is greatly decreased.

The economic assessment evaluation of utilizing broiler litter as a feedstuff for ruminants is summarized in Table 115. The maximum level of incorporation depends upon the treatment utilized prior to use as a feedstuff and varies considerably. "Optimum" levels of incorporation could not be determined from the existing data. The estimated gross value of broiler litter is about two times its fertilizer value, and comparable to the gross value of corn silage and forages (dry matter basis).

TABLE 113. SUMMARY OF THE MAXIMUM AND "OPTIMUM" LEVELS OF INCORPORATING ANIMAL MANURES INTO LAYING HEN DIETS AND RUMINANT RATIONS, BASED ON ANIMAL PERFORMANCE

Type of Manure	Species Fed	Maximum Level, %	"Optimum" Level, %
DPW	Laying Hen	14-20	10-12.5
	Laying Hen*	8-11	5
	Steers	5	<5
	Heifers	†	†
	Dairy Cows	10-12	<11-12
Broiler Litter			
As Collected	Steers	18-22	<18-22
Dried	Steers	11-16	< 10
Ensiled	Steers	25-52	10-30
	Heifers	1-10	< 10
Composted	Beef Heifers	75	†
	Brood Cows	80	†
Beef Cattle Manure			
As Collected	Steers	0	0
Dried	Steers	0	0
Ensiled			
vs corn silage	Steers	16-24	†
vs corn grain	Ruminants	†	†

* With lard or soybean oil supplementation
† Cannot be determined from existing data

TABLE 114. SUMMARY OF THE ESTIMATED ECONOMIC VALUE OF DPW

Species Fed	Conventional Feedstuff Comparable to	Estimated Value of DPW Based on Nutrient Content (Dollars per Tonne of)* dry matter	Fertilizer Value of DPW (dollars per Tonne of dry matter)†	Economic Level of Incorporation, %		Estimated Gross Value of DPW Based on Animal Performance (dollars per Tonne of dry matter) ‡	
				Maximum	"Optimum"	Maximum Level	Optimum Level
Laying Hen	Meat and Bone Meal	117	47	20-35	10-12.5	48	280
Laying Hen §	Meat and Bone Meal	117	47	12-16	5	16	186
Steers	Silage and Forages	58 and 80	47	< 5	#	31	#
Heifers	Silage and Forages	58 and 80	47	#	#	#	#
Dairy Cows	Silage and Forages	58 and 80	47	10-25	5-10	166	225

* See Table 17 for Estimated Value Based on Nutrient Content
† See Appendix D for Fertilizer Value Determination
‡ See Table 53 for Estimated Value Based on Animal Performance
§ With Lard or Soybean Oil Supplementation
# Cannot be Determined From Existing Data

TABLE 115. SUMMARY OF THE ESTIMATED ECONOMIC VALUE OF BROILER LITTER

Treatment of Litter	Species Fed	Conventional Feedstuff Comparable to	Estimated Value of Litter Based on Nutrient Content (dollars per tonne of dry matter)*	Fertilizer Value of Litter (dollars per Tonne of dry matter)†	Maximum Economic Level of Incorporation, %	Estimated Gross Value Of Litter Based On Animal Performance (dollars per tonne of dry matter)‡
As Collected	Steers	Silages and Forages	58 and 80	40	18-22	72
Dried	Steers	Silages and Forages	58 and 80	40	11-16	90
Ensiled	Steers	Silages and Forages	58 and 80	40	25-52	§
	Heifers	Silage and Forages	58 and 80	40	1-10	90
Composted	Beef Heifers	Silage and Forages	58 and 80	40	75	81
	Brood Cows	Silage and Forages	58 and 80	40	80	72

* See Table 17 For Estimated Value Based on Nutrient Content.
† See Appendix D for Fertilizer Value Determination
‡ See Table 73 for Estimated Value Based on Animal Performance
§ Cannot be Determined from Existing Data

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The economic assessment evaluation of utilizing beef cattle manure as a feedstuff for ruminants is summarized in Table 116. The utilization of as collected or dried beef cattle manure is inappropriate because of adverse animal performance. This type of beef cattle manure has more value as a fertilizer than as a potential feedstuff. The use of ensiled beef cattle manure as a feedstuff can be a sound nutritional practice; however, economically it appears not to compete with the low cost of corn silage or forages. An economic savings might be realized when ensiled beef cattle manure is utilized at low levels as a substitute for corn grain.

The evaluation of using other processed animal manures as feedstuffs is summarized in Table 117. Economic benefits may be realized by using liquid aerobically digested animal manures as the source of drinking water for poultry or swine. However, the nutrient value of this material and enhancement methods are poorly defined. Use of anaerobically stabilized animal manures as feedstuffs is inappropriate because of poor animal performance results. The utilization of dairy cow and beef cattle manure screenings requires further investigation to delineate their nutritive, economic and environmental value. Cereco products are not commercially available in the United States today; however, plans exist for the products to be manufactured by a new process and the utilization of these products as feedstuffs may be feasible in the future.

The utilization of animal manures as feedstuffs does not appear to be an efficient waste management practice to reduce potential environmental quality problems caused by the discharge of animal manures. Only a low level of such manures will be incorporated into animal rations and the potential pollution abatement impact will be minimal.

TABLE 116. SUMMARY OF THE ESTIMATED ECONOMIC VALUE OF BEEF CATTLE MANURE

Treatment of Manure	Species Fed	Conventional Feedstuff Comparable to	Estimated Value of Manure Based on Nutrient Content (Dollars per tonne of dry matter)*	Fertilizer Value of Manure (dollars per tonne of dry matter)†	Maximum Economic Level of Incorporation,%	Estimated Gross Value of Manure Based on Animal Performance (dollars per tonne of dry matter)‡
As Collected	Steers	Silage and Forages	58 and 80	25	0	- 15
Dried	Steers	Silage and Forages	58 and 80	25	0	-256
Ensiled	Steers§	Silage and Forages	58 and 80	25	0	-135
	Ruminants#	Silage and Forages	58 and 80	25	**	122

* See Table 17 for estimated value based on nutrient content
† See Appendix D for fertilizer value determination
‡ Estimated value represents mean of all studies evaluated, see Table 87
§ Compared to corn silage fed controls
# Compared to corn grain fed controls
** Cannot be determined from existing data

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TABLE 117. SUMMARY OF THE ESTIMATED ECONOMIC VALUE OF PROCESSED ANIMAL MANURES

Type of Processed Manure	Species Fed	Estimated Gross Value of Manure per Tonne, Dry Matter Basis (dollars)*
Aerobically Digested	Swine	262-296
	Laying Hens	273
Anaerobically Digested		
Wet Centrifuge Cake	Steers	- 102
Dry Centrifuge Cake	--	†
Effluent	Steers	- 626
Manure Screenings		
Beef Cattle	Ruminants	†
Dairy Cow	Ruminants	†
Cereco Process		
CI	Steers	- 6
CII	Steers	122

* See Table 112

† Value cannot be determined at this time

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APPENDIX A

REFERENCES FOR THE NUTRIENT, MINERAL AND AMINO ACID COMPOSITION OF ANIMAL MANURES

In the following tables, the references for the nutrient, mineral and amino acid composition of animal manures are presented:

TABLE A-1. REFERENCES FOR DRIED POULTRY WASTE (DPW)

TABLE A-2. REFERENCES FOR BROILER LITTER

TABLE A-3. REFERENCES FOR DAIRY COW MANURE

TABLE A-4. REFERENCES FOR BEEF CATTLE MANURE

TABLE A-5. REFERENCES FOR CERECO PRODUCTS

TABLE A-1. REFERENCES FOR NUTRIENT, MINERAL, AND AMINO ACID COMPOSITION OF DRIED POULTRY WASTE (DPW), TABLES 4, 5, and 6

Source	Reference
1	Biely *et al*. (1972)
2	Bucholtz *et al*. (1971)
3	Bull and Reid (1971)
4	Capar *et al*. (1978)
5	Chang and Rible (1975)
6	Cullison *et al*. (1976)
7	El-Sabban *et al*. (1969)
8	Ensminger and Olentine (1978)
9	Essig (1977)
10	Fairbain (1970)
11	Flegal and Zindel (1971)
12	Goering and Smith (1977)
13	Hodgetts (1971)
14	Kali *et al*. (1975)
15	Long *et al*. (1969)
16	Lowman and Knight (1970)
17	Nesheim (1972)
18	Oliphant (1974)
19	Oltjen and Dinius (1976)
20	Perez-Aleman *et al*. (1971)
21	Polin *et al*. (1971)
22	Price (1972)
23	Smith (1973)
24	Surbrook *et al*. (1971)
25	Tinnimit et al. (1972)
26	Van Soest and Robertson (1976)
27	Zindel *et al*. (1977)

TABLE A-2. REFERENCES FOR NUTRIENT AND MINERAL COMPOSITION OF BROILER LITTER, TABLES 7, 8 and 9

Source	Reference
1	Ammerman et al. (1966)
2	Bhargava and O'Neil (1975)
3	Bhattacharya and Fontenot (1965)
4	Bhattacharya and Fontenot (1966)
5	Brugman _et_ _al_. (1964)
6	Capar _et_ _al_. (1978)
7	Caswell _et_ _al_. (1978)
8	Cross (1977)
9	Cross _et_ _al_. (1978)
10	Cullison _et_ _al_. (1973)
11	Cullison _et_ _al_. (1976)
12	El-Sabban _et_ _al_. (1969)
13	Fairbairn (1970)
14	Fontenot (1977)
15	Fontenot _et_ _al_. (1971)
16	Free (1977)
17	Galmez _et_ _al_. (1970)
18	Harmon _et_ _al_. (1975)
19	Kali _et_ _al_. (1975)
20	Oliphant (1974)
21	Ruffin (1977)
22	Smith and Calvert (1976)
23	Stuedemann _et_ _al_. (1975)
24	Van Soest (1980)

TABLE A-3. REFERENCES FOR NUTRIENT AND MINERAL COMPOSITION OF DAIRY COW MANURE, TABLES 10, 11 and 12

Source	Reference
1	Chang and Rible (1975)
2	Fenner and Archibald (1959)
3	Goering and Smith (1977)
4	Grant (1975)
5	Kali *et al*. (1975)
6	Magdoff *et al*. (1978)
7	Randall *et al*. (1975)
8	Smith *et al*. (1970)
9	Smith *et al*. (1971)
10	Surbrook *et al*. (1971)
11	Thomas *et al*. (1970)
12	Tinnimit *et al*. (1972)
13	Van Soest and Robertson (1976)
14	Whetstone *et al*. (1974)
15	Van Soest (1980)

TABLE A-4. REFERENCES FOR NUTRIENT, MINERAL, AND AMINO ACID COMPOSITION OF BEEF CATTLE MANURE, TABLES 13, 14, and 15

Source	Reference
1	Adriano (1975)
2	Anthony (1969)
3	Anthony (1971)
4	Blair and Knight (1973)
5	Braman (1975)
6	Bucholtz et al. (1971)
7	Capar *et al*. (1978)
8	Chang and Rible (1975)
9	Ensminger and Olentine (1978)
10	Harpster *et al*. (1978)
11	Johnson (1972)
12	Kali *et al*. (1975)
13	Lipstein and Borstein (1973)
14	Lucas *et al*. (1974)
15	McClure *et al*. (1971)
16	Newton *et al*. (1977)
17	Schake *et al*. (1974)
18	Schake *et al*. (1977)
19	Tinnimit *et al*. (1972)
20	Van Soest and Robertson (1976)
21	Westing and Brandenberg (1974)
22	Whetstone *et al*. (1974)

TABLE A-5. REFERENCES FOR NUTRIENT CHARACTERISTICS OF CERECO SILAGE AND CERECO PROTEIN, TABLES 28, 29, and 30

Source	Reference
1	Kienholz *et al*. (1975)
2	Lambeth (1975)
3	Lambeth *et al*. (1974)
4	Seckler and Ward (1974)
5	Wallick *et al*. (1978)
6	Ward *et al*. (1975)
7	Post and Ward (1975)
8	Van Soest (1980)

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APPENDIX B

COMPOSITION OF CONVENTIONAL FEEDSTUFFS

The composition of energy feeds (corn and sorghum grain), protein feeds (soybean and cottonseed meal), and silage and forages (corn silage, timothy, alfalfa and bermudagrass hay) used in the comparison of as collected and other processed animal manures (Sections 5 and 6) is presented in Table B-1.

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TABLE B-1. COMPOSITION OF CONVENTIONAL FEEDSTUFFS*

	Percent of Dry Matter											Mcal/kg D.M.
Feedstuff	Crude Protein	Digestible Protein	Amino Acids	Ether Extract	Total Ash	Crude Fiber	NFE	TDN	ADF†	NDF†	Lignin†	Metabolizable Energy
ENERGY FEEDS:												
Corn, grain (all analyses)	10.9	8.0	6.37	4.5	1.4	2.4	81.4	93	3.2	20.3	1.0	3.36
Sorghum, grain (all analyses)	12.6	8.8	6.66	3.1	1.9	2.7	79.6	89	5	23	2	3.21
PROTEIN FEEDS:												
Soybean meal (49%)	47.6	39.7	29.05	1.5	6.9	4.7	39.4	84	5.1	14	‡	3.02
Cottonseed meal (41%)	44.0	35.2	28.80	5.0	6.6	12.1	32.3	75	20	28	5.8	2.71
FORAGES:												
Corn silage (all analyses)	7.0	3.6	‡	2.8	5.3	25.5	59.3	68	27	45	5	2.47
Timothy hay (mid-bloom)	9.5	5.4	‡	2.6	6.5	34.1	47.4	59	37.3	68.2	4	2.14
Alfalfa hay (mid-bloom)	18.8	14.0	8.81	3.2	8.6	28.8	40.6	56	36.1	47.5	9	2.24
Bermudagrass hay (sun-cured)	9.8	5.0	‡	2.0	7.9	28.2	52	49	38	78	12	1.77

*Ensminger and Olentine (1978).
†Van Soest (1980).
‡Not reported.

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APPENDIX C

FEEDING STUDIES NOT EVALUATED

In the following tables, feeding trials that could not be evaluated and the reasons for not evaluating them are presented:

TABLE C-1. DRIED POULTRY WASTE (DPW) FED TO LAYING HENS

TABLE C-2. DRIED POULTRY WASTE (DPW) FED TO STEERS

TABLE C-3. DRIED POULTRY WASTE (DPW) FED TO DAIRY COWS

TABLE C-4. DRIED POULTRY WASTE (DPW) FED TO HEIFERS

TABLE C-5. BROILER LITTER FED TO RUMINANTS

TABLE C-6. CATTLE MANURE FED TO RUMINANTS

TABLE C-7. ENSILED OR COMPOSTED CATTLE MANURE FED TO RUMINANTS

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TABLE C-1. DRIED POULTRY WASTE (DPW) FED TO LAYING HENS

Source	Reason for Not Evaluating Study
Quisenberry and Bradley (1968)	Reprint of study not available
Flegal & Zindel (1969)	Abstract only, insufficient data
Fairbairn (1970)	Lack of egg production data
Ousterhouse & Presser (1971)	Abstract only, insufficient data
Bergdoll (1972)	Lack of dietary ingredients
Price (1972)	Lack of dietary ingredients and egg production data
Pryor & Connor (1974)	Lack of nutritional results
Waldroup & Hazen (1974)	Lack of dietary ingredients
Flegal & Zindel (1977)	Lack of egg production data
Galal _et al_. (1977)	Abnormal treatment (autoclaving) of DPW
Lee & Bolton (1977)	Uncommon diet ingredients
Auckland (1978)	Uncommon diet ingredients
Lee _et al_. (1978)	Uncommon diet ingredients
Ogunmoder & Afolabi (1978)	Uncommon diet ingredients

TABLE C-2. DRIED POULTRY WASTE (DPW) FED TO STEERS

Source	Reason for Not Evaluating Study
Bull and Reid (1971)	Lack of data on dietary ingredients
Smith (1974)	Abstract only, insufficient data
Clark _et_ _al_. (1975)	Abstract only, insufficient data
Anderson _et_ _al_. (1976)	Reprint of study not available
Dethrow _et_ _al_. (1976)	Abstract only, insufficient data
Lamm _et_ _al_. (1976)	Abstract only, insufficient data
Essig (1977)	Lack of data on dietary ingredients
Fairbrother _et_ _al_. (1978)	Abstract only, insufficient data
Koenig _et_ _al_. (1978)	Pretreatment with formalin altered composition of DPW
Smith _et_ _al_. (1979)	Insufficient nutritional data

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TABLE C-3. DRIED POULTRY WASTE (DPW) FED TO DAIRY COWS

Source	Reason for Not Evaluating Study
Bull and Reid (1971)	Lack of data on dietary ingredients
Kneale and Garstang (1973)	Abstract only, insufficient data
Smith and Fries (1973)	Abstract only, insufficient data
Clanton and Jones (1975)	Reprint of study not available
Kali *et al*. (1975)	Lack of data on animal body weights
Kristensen *et al*. (1976)	Reprint of study not available
Calvert and King (1977)	Abstract only, insufficient data

TABLE C-4. DRIED POULTRY WASTE (DPW) FED TO HEIFERS

Source	Reason for Not Evaluating Study
Bucholtz *et al*. (1971)	Lack of data on dietary ingredients
Tinnimit and Thomas (1972)	Abstract only, insufficient data
Clanton and Jones (1975)	Reprint of study not available
Kali *et al*. (1975)	Lack of data on animal body weights
Essig *et al*. (1977)	Abnormal performance of control group

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TABLE C-5. BROILER LITTER FED TO RUMINANTS

Source	Reason for Not Evaluating Study
Drake *et al*. (1965)	Abstract only, insufficient data
Cullison *et al*. (1973)	Abstract only, insufficient data
Caswell *et al*. (1974)	Abstract only, insufficient data
Fontenot *et al*. (1975)	Results reported in an earlier study
Tagari *et al*. (1976)	Unusual feedstuff
Wooden and Algeo (1976)	Abstract only, insufficient data
Cross (1977)	More complete results reported in later study
Cross *et al*. (1977)	Abstract only, insufficient data
Fontenot (1977)	Results reported in earlier study
Kelley *et al*. (1977)	Abstract only, insufficient data
Chambers *et al*. (1978)	Abstract only, insufficient data

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TABLE C-6. CATTLE MANURE FED TO RUMINANTS

Source	Reason for Not Evaluating Study
Anthony (1970)	Manure washed and cooked
Lucas *et al*. (1974)	No animal performance data
Albin and Sherrod (1975)	No animal performance data
Braman (1975)	Abstract only, insufficient data
Ward and Muscato (1976)	Insufficient nutritional data
Pinkerton *et al*. (1976)	Abstract only, insufficient data
Anthony (1977)	Results reported in an earlier study
Richter and Shirley (1977)	Abstract only, insufficient data
Westing *et al*. (1978)	Abstract only, insufficient data

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TABLE C-7. ENSILED OR COMPOSTED CATTLE MANURE FED TO RUMINANTS

Source	Reason for Not Evaluating Study
Anthony (1968, 1971, 1973, 1974)	Abstracts only, or results reported in earlier studies
Blandel and Anthony (1969)	Abstract only, insufficient data
Moore and Anthony (1970)	Abstract only, insufficient data
Anthony *et al*. (1973)	Abstract only, insufficient data
McClure *et al*. (1973)	Abstract only, insufficient data
Vetter and Burroughs (1974)	Abstract only, insufficient data
Newton *et al* (1976)	Abstract only, insufficient data
Yokoyama and Nummy (1976)	Abstract only, digestibility trial
Braman and Abe (1977)	Abstract only, insufficient data
Lamm *et al*. (1977)	Cattle manure treated with alkali
Farguhar *et al*. (1978)	Abstract only, insufficient data
Lamm *et al*. (1979)	No animal performance data

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APPENDIX D

FERTILIZER VALUE OF ANIMAL MANURES

In the following tables, the fertilizer content of animal manures and their monetary values are presented:

TABLE D-1.	FERTILIZER COMPOSITION OF ANIMAL MANURES
TABLE D-2.	NUTRIENT QUANTITY OF ANIMAL MANURES AS EXCRETED AND FERTILIZER VALUE
TABLE D-3.	NUTRIENT QUANTITY OF ANIMAL MANURES (DRY MATTER BASIS) AND FERTILIZER VALUE

TABLE D-1. FERTILIZER COMPOSITION OF ANIMAL MANURES* (percent of dry matter)

Nutrient	Caged laying hen manure	Broiler litter	Dairy cow manure	Beef Cattle manure
Nitrogen	4.48	4.29	2.45	2.64
Phosphorus	2.29	1.81	0.65	0.80
Potassium	2.24	1.78	1.42	2.25

*Plant nutrient content as reported in Section 5.

TABLE D-2. NUTRIENT QUANTITY OF ANIMAL MANURES AS EXCRETED AND FERTILIZER VALUE*

Nutrient	Caged laying hen manure, 25% dry matter	Broiler litter, 80% dry matter	Dairy cow manure, 15.5% dry matter	Beef cattle manure, 21% dry matter
	Kilograms per tonne			
Nitrogen†	11.20	34.32	3.80	5.54
Phosphorus†	5.72	14.48	1.01	1.68
Potassium†	5.60	14.24	2.20	4.72
	Dollars per tonne			
Fertilizer value	11.72	32.32	3.23	5.33

*Based upon prices from Agway, Inc., Ithaca, New York, February 1979. Cost of N = $0.441/kg; P = $0.900/kg; K = $0.292/kg.

†Nutrient concentrations calculated utilizing raw waste characteristics presented in Section 5.

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TABLE D-3. NUTRIENT QUANTITY OF ANIMAL MANURES (DRY MATTER BASIS) AND FERTILIZER VALUE*

Nutrient	Caged Laying Hen Manure	Broiler Litter	Dairy Cow Manure	Beef Cattle Manure
	kilograms per tonne			
Nitrogen	44.8	42.9	24.5	26.4
Phosphorus	22.9	18.1	6.5	8.0
Potassium	22.4	17.8	14.2	22.5
	dollars per tonne			
Fertilizer Value	46.91	40.41	20.80	25.41

* Based upon prices from Agway, Inc., Ithaca, New York, February, 1979. Cost of N = \$0.441/kg; P = \$0.900/kg; K = \$0.292/kg

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APPENDIX E

MARKET PRICES OF FEEDSTUFFS

In the following tables, the market prices of the feedstuff utilized in the economic assessment of the value of animal manures are presented:

TABLE E-1. MARKET PRICES REPORTED IN FEEDSTUFFS, JANUARY 15, 1979

TABLE E-2. MARKET PRICES OBTAINED FROM AGWAY INC., SYRACUSE, N.Y. JANUARY 24, 1979

TABLE E-3. MARKET PRICES OBTAINED FROM CORNELL UNIVERSITY AND THE NEW YORK TIMES

TABLE E-1. MARKET PRICES REPORTED IN FEEDSTUFFS, JANUARY 15, 1979

Feedstuff	Dollars per tonne
Alfalfa meal, 17%	127.87
Barley, ground	112.88
Beet pulp	140.65
Bone meal	301.67
Citrus pulp	109.79
Corn, distillers solubles	155.87
Corn, gluten meal, 60%	275.58
Corn, grain, No. 2	106.70
Cottonseed meal, 41%	205.91
Fish meal, menhaden	438.50
Meat and bone meal	250.45
Molasses	102.07
Oats, rolled	207.68
Peanut meal	220.68
Poultry by-product meal	279.99
Rice, mill feed	42.44
Salt	40.79
Sorghum, grain	96.78
Soybean meal, 44%	198.86
Soybean meal, 49%	215.83
Tallow, prime	455.70
Urea	173.94
Wheat, bran	117.07
Wheat, ground	163.36
Wheat, middlings	115.96
Wheat, shorts	122.25
Yellow grease	408.96

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TABLE E-2. MARKET PRICES OBTAINED FROM AGWAY INC., SYRACUSE, N.Y., JANUARY 24, 1979

Feedstuff	Dollars per tonne
Alfalfa hay	71.66
Bermudagrass hay	71.65
Bermudagrass pellets	137.79
Brewers yeast	716.62
Corn and cob meal	121.25
Corn, cobs	13.78
Corn, ears	71.65
Corn, silage	14.88
Corn, stover	17.09
Cottonseed hulls	79.92
Dicalcium phosphate	341.72
Limestone	55.12
Peanut hulls	24.91
Rice hulls	28.11
Salt, trace mineralized	88.41
Soybean hulls	88.18
Timothy hay	71.65
Vitamin premix	66.36
Wheat, straw	55.12

TABLE E-3. MARKET PRICES OBTAINED FROM CORNELL UNIVERSITY AND NEW YORK TIMES

	Feedstuff	Dollars per tonne
Cornell University (January 24, 1979)	Cerelose, glucose	396.83
	Corn, starch	352.08
New York Times (March 29, 1979)	Corn Oil	727.53
	Soybean oil	655.88

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APPENDIX F

COST ESTIMATES FOR DRYING LAYING HEN AND DAIRY CATTLE MANURES

INTRODUCTION

Animal manures as produced are biologically active materials which are bulky and difficult to handle as a solid due to high levels of moisture. For example, moisture contents expressed on a wet basis (WB) of caged laying hen and dairy cattle manures average 75% and 90% respectively. These high moisture levels and the associated characteristics noted above preclude the direct use of manures as components of manufactured feeds or the marketing of manures as fertilizers/soil conditioners for horticultural activities. In both instances, drying is a necessary prerequisite and the associated costs represent an important factor in the assessment of the economic feasibility of the utilization alternatives noted above.

Although several estimates of manure-drying costs are available in the literature, a review of this information resulted in the conclusion that a new cost analysis was necessary. First, updating of published estimates to reflect the impacts of inflation and rising energy costs was not possible due to the absence of detailed descriptions of assumptions and methodology. Second, the effect of utilization, as related to dryer capacity, on unit costs had not been examined. The objective of the following is to describe the methodology and assumptions employed and to present and discuss this analysis of the cost of drying caged laying hen and dairy cattle manures.

METHODOLOGY

To accurately reflect the cost of drying animal manures as a commercial enterprise, this cost analysis was based on information obtained from manufacturers of equipment which is marketed for the drying of animal manures and is designed to meet prevailing air quality standards. Three firms currently are active in this field: The Hamada Manufacturing Company, a Japanese firm represented by the Wolverine Manufacturing Company, Grand Haven, Michigan; The Heil Company, Milwaukee, Wisconsin; and Aeroglide Corporation, Raleigh, North Carolina.

Each firm was requested to provide the following information for each dryer model marketed for drying animal manures.

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A. Purchase price of the drying unit, including feed hoppers, conveyors, etc., and air pollution control equipment.

B. Building site required to house drying units.

C. Evaporative capacity.

D. Fuel consumption.

E. Connected electrical load.

Response to this request by the Hamada representative and the Heil Company was excellent. Unfortunately, it was not possible to obtain adequate information from the Aeroglide Corporation to include their manure dryers in this analysis. The information provided by Hamada and Heil is summarized in Tables F-1 and F-2. Structural costs were estimated from minimum building size recommendations using a construction cost figure of \$66.67 per m^2 (\$6.00 per ft^2) (Guest, 1979) (Table F-3).

Price quotations for the various sizes of dryers (Table F-1 and F-2) and the cost estimates for associated structures (Table F-3) were used to calculate annual fixed costs for each dryer. The assumptions employed in annual fixed-cost calculations are outlined in Table F-4. Operating costs were determined from fuel consumption and electrical demand values presented in Tables F-1 and F-2. Prices used for No. 2 fuel oil and electricity were \$0.21 per ℓ(\$0.79 per gal) and \$0.0405 per kwhr, respectively. These prices are average costs to consumers excluding taxes for Ithaca, New York, August, 1979. Production estimates assumed input moisture content of caged laying hen and dairy cattle manures at 75% WB and 90% WB respectively. For both types of manure, output moisture content was assumed to be 15% WB. The thermal efficiency of each dryer was calculated from evaporative capacity and fuel oil consumption values (Tables F-1 and F-2) assuming the average heat content of No. 2 fuel oil to be 40,583 kJ per ℓ (Mark's Standard Handbook for Mechanical Engineers, 1978).

RESULTS

Estimated annual fixed costs for various sizes of manure dryers manufactured by the Hamada and Heil Companies are presented in Tables F-5 and F-6. These dryers range in evaporative capacity from 247 kg H_2O per hr to 8172 kg H_2O per hr. Table F-7 contains estimated annual fixed costs for the structures required to house the various sizes of manure dryers considered in this study. Total annual fixed costs for drying equipment and building are summarized in Table F-8. Examination of total annual fixed costs per unit of evaporative capacity versus evaporative capacities of various size dryers considered (Figure F-1) shows a typical decrease in unit costs as total capacity increases.

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TABLE F-1. SUMMARY OF INFORMATION PROVIDED BY THE HAMADA COMPANY

Model	Purchase Price Quoted, $	Building, Size Required, m^2	Evaporative Capacity, kg H_2O/hr	Fuel Consumption* ℓ/hr	Connected Electrical Load, kw
FS-S3	55,100	90	247	20	5
FS-1	68,460	90	424	40	10
FS-2	132,825	243	635	60	16
FS-3	185,950	291.6	1271	130	35
FS-4	214,000	382.5	1906	200	53
FS-5	280,000	594	3530	320	60

* No. 2 Fuel Oil

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TABLE F-2. SUMMARY OF INFORMATION PROVIDED BY THE HEIL COMPANY

Model	Purchase Price Quoted, $	Building, Size Required, m^2	Evaporative Capacity, kg H_2O/hr	Fuel Consumption* ℓ/hr	Connected Electrical Load, kw
SD45-12	58,170	93	454	39	14.7
SD75-22	278,338	409	2724	234	39.7
SD85-25	357,071	447	4086	351	44.8
SD105-32	403,732	483	8172	702	90

* No. 2 Fuel Oil

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TABLE F-3. ESTIMATED STRUCTURAL COSTS FOR HOUSING HAMADA AND HEIL MANURE DRYING UNITS.

Manufacturer	Model	Building, Size Required, m^2	Construction* Cost, $
Hamada	FS-S3	90	6,000
	FS-1	90	6,000
	FS-2	243	16,200
	FS-3	292	19,500
	FS-4	382	25,500
	FS-5	594	39,600
Heil	SD45-12	90	6,000
	SD75-22	408	27,200
	SD85-25	447	29,800
	SD105-32	483	32,200

*at $66.67 per m^2 ($6.00 per ft^2)

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TABLE F-4. ASSUMPTIONS USED IN CALCULATING ANNUAL FIXED COSTS FOR MANURE DRYERS AND ASSOCIATED STRUCTURES

Estimated Useful Life

Dryer - 10 yr.

Structure - 20 yr.

Amortization Rate

10% per year assuming no salvage value

Taxes and Insurance

Dryer - 3.5% of initial investment per year

Structure - 3.5% of initial investment per year

Maintenance and Repairs

Dryer - 2.0% of initial investment per year

Structure - 1.0% of initial investment per year

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TABLE F-5. ESTIMATED ANNUAL FIXED COSTS FOR HAMADA MANURE DRYERS

Model	Purchase Price, Quoted, $	Annual Capital* Cost, $	Taxes & † Insurance, $	Maintenance ‡ & Repairs, $	Annual Fixed Cost, $
FS-S3	55,100	8,968	1,928	1,102	11,998
FS-1	68,460	11,142	2,396	1,369	14,907
FS-2	132,825	21,617	4,649	2,656	28,922
FS-3	185,950	30,263	6,508	3,719	40,490
FS-4	214,000	34,828	7,490	4,280	46,598
FS-5	280,000	45,570	9,800	5,600	60,970

* Amortized at 10% per year over an estimated useful life of 10 years with no salvage value.

† Estimated at 3.5% of initial investment per year.

‡ Estimated at 2% of initial investment per year.

TABLE F-6. ESTIMATED ANNUAL FIXED COSTS FOR HEIL MANURE DRYERS

Model	Purchase Price, Quoted, $	Annual Capital* Cost, $	Taxes & † Insurance, $	Maintenance ‡ & Repairs, $	Annual Fixed Cost, $
SD45-12	58,170	9,467	2,036	1,163	12,666
SD75-22	278,338	45,300	9,742	5,567	60,609
SD85-25	357,071	58,113	12,497	7,141	77,751
SD105-32	403,732	65,707	14,131	8,075	87,913

* Amortized at 10% per year over an estimated useful life of 10 years with no salvage value.

† Estimated at 3.5% of initial investment per year.

‡ Estimated at 2% of initial investment per year.

TABLE F-7. ESTIMATED ANNUAL FIXED COSTS OF STRUCTURES FOR MANURE DRYERS

Manufacturer	Model	Investment, $	Annual Capital* Cost, $	Taxes &† Insurance, $	Maintenance‡ & Repairs, $	Annual Fixed Cost, $
Hamada	FS-S3	6,000	705	210	60	975
	FS-1	6,000	705	210	60	975
	FS-2	16,200	1,903	567	162	2,632
	FS-3	19,440	2,283	680	194	3,157
	FS-4	25,500	2,995	892	255	4,142
	FS-5	39,600	4,651	1,386	396	6,433
Heil	SD45-12	6,000	705	210	60	975
	SD75-22	27,200	3,195	952	272	4,419
	SD85-25	29,800	3,500	1,043	298	4,841
	SD105-32	32,200	3,782	1,127	322	5,231

* Amortized at 10% per year over an estimated useful life of 20 years with no salvage value.

† Estimated at 3.5% of initial investment per year.

‡ Estimated at 1% of initial investment per year.

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TABLE F-8. SUMMARY OF ESTIMATED ANNUAL FIXED COSTS FOR MANURE DRYERS AND ASSOCIATED STRUCTURES

Manufacturer	Model	Annual Fixed Cost, $		Total Annual Fixed Cost, $
		Dryer	Building	
Hamada	FS-S3	11,998	975	12,973
	FS-1	14,907	975	15,882
	FS-2	28,922	2,632	31,554
	FS-3	40,490	3,157	43,647
	FS-4	46,598	4,142	50,740
	FS-5	60,970	6,433	67,403
Heil	SD45-12	12,666	975	13,641
	SD75-22	60,609	4,419	65,028
	SD85-25	77,751	4,841	82,592
	SD105-32	87,913	5,231	93,144

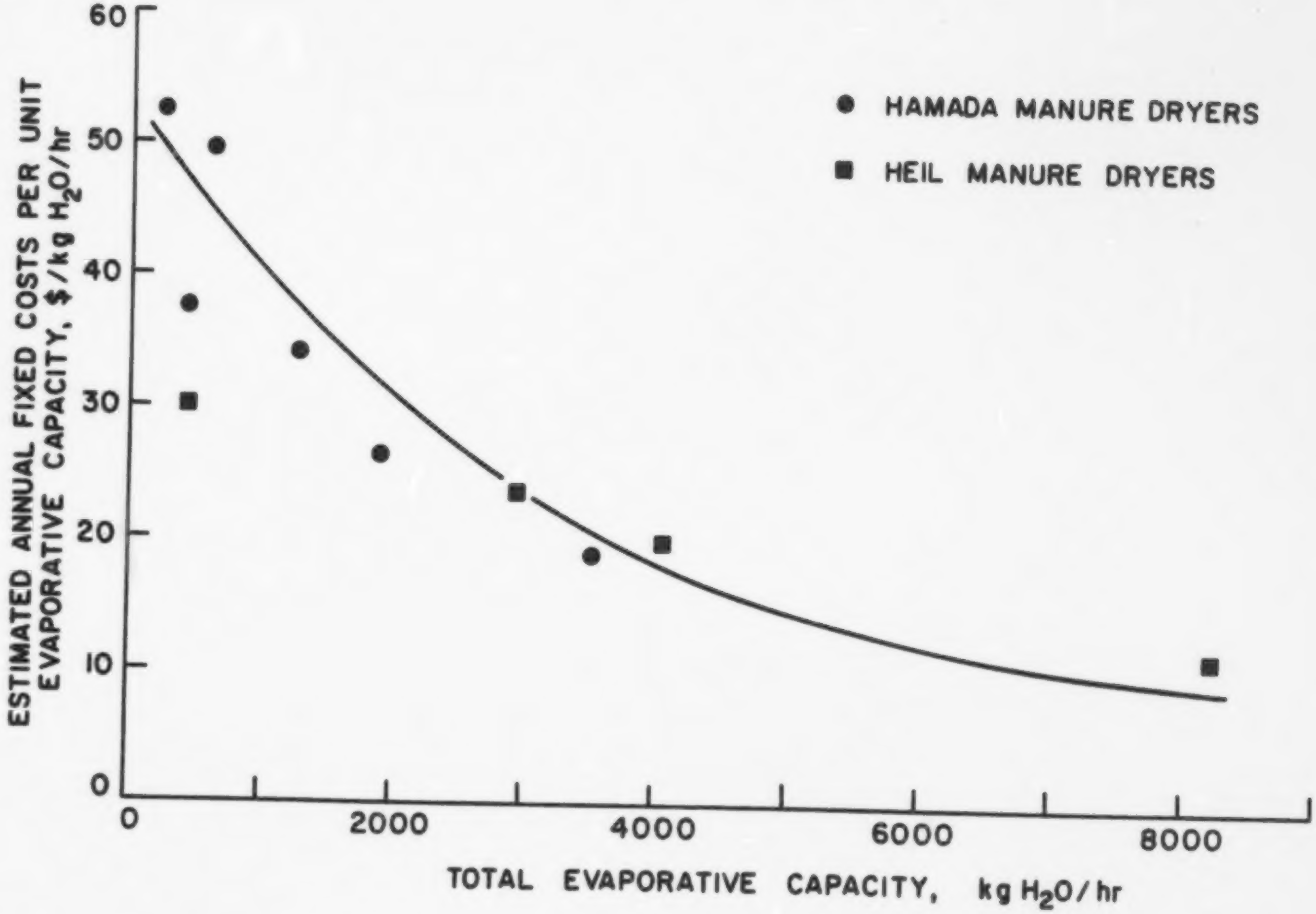

Figure F-1. The Relationship Between Annual Fixed Costs per Unit Evaporative Capacity and Total Evaporative Capacity For Hamada and Heil Manure Dryers

Calculated rates of production of dried caged laying hen and dairy cattle manures for Hamada and Heil manure dryers are presented in Tables F-9 and F-10 respectively. The impact of the higher initial moisture content of dairy cattle manure as compared to laying hen manure should be noted. Estimated unit fixed costs for drying caged laying hen and dairy cattle manures (Table F-11) were calculated from total annual fixed costs and product output estimates for various sizes of drying units. The unit fixed costs presented in Table F-11 show that the economies of scale with respect to fixed costs are substantial in drying animal manures.

Estimates of operating costs per hour and per tonne of dried product for both caged laying hen and dairy manure based on fuel consumption and connected electrical load (Tables F-1 and F-2) for various sizes of manure dryers are summarized in Table F-12. Variation between individual units reflects differences in thermal efficiencies. Calculated thermal efficiencies based on evaporative capacity and fuel oil consumption ranged between 60.8% and 78.8%.

Total estimated costs for drying caged laying hen and dairy cattle manures are summarized in Table F-13. These values provide a basis for assessing the economic feasibility of drying these manures for use as components in manufactured feeds or for sale as fertilizers/soil conditioners. Use of natural gas in place of No. 2 fuel oil will reduce operating costs significantly but will result in only nominal reductions of total drying costs for small units due to high unit fixed costs.

TABLE F-9. ESTIMATED PRODUCTIVE CAPACITY OF HAMADA MANURE DRYERS

Model	Evaporative Capacity, kg H_2O/hr	Caged Laying Hen Manure, kg/hr		Dairy Cattle Manure, kg/hr	
		Input*	Output †	Input‡	Output †
FS-S3	247	350	103	280	33
FS-1	424	600	176	480	56
FS-2	635	900	265	720	85
FS-3	1,271	1,800	529	1,440	169
FS-4	1,906	2,700	794	2,160	254
FS-5	3,530	5,000	1,470	4,001	471

* 75% moisture, WB.

† 15% moisture, WB.

‡ 90% moisture, WB.

TABLE F-10. ESTIMATED PRODUCTIVE CAPACITY OF HEIL MANURE DRYERS

Model	Evaporative Capacity, kg H_2O/hr	Caged Laying Hen Manure, kg/hr		Dairy Cattle Manure, kg/hr	
		Input*	Output †	Input‡	Output †
SD45-12	454	643	189	514	60
SD75-22	2,724	3,858	1,134	3,087	363
SD85-25	4,086	5,787	1,701	4,631	545
SD105-32	8,172	11,574	3,402	9,262	1,090

* 75% moisture, WB.

† 15% moisture, WB.

‡ 90% moisture, WB.

TABLE F-11. ESTIMATED UNIT FIXED COSTS FOR DRYING CAGED LAYING HEN AND DAIRY CATTLE MANURES

Manufacturer	Model	Unit Fixed Costs, $/Tonne Output* Caged Laying Hen	 Dairy Cattle
Hamada	FS-S3	62.98	196.56
	FS-1	45.12	141.80
	FS-2	59.54	185.61
	FS-3	41.25	129.13
	FS-4	31.95	99.88
	FS-5	22.93	71.55
Heil	SD45-12	36.09	113.68
	SD75-22	28.67	89.57
	SD85-25	24.28	75.77
	SD105-32	13.69	42.73

*Assumes 2,000 hr. of dryer operation per year

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TABLE F-12. ESTIMATED OPERATING COSTS FOR HAMADA AND HEIL MANURE DRYERS

Manufacturer	Model	Fuel Oil Cost, \$/hr*	Electrical Cost, \$/hr†	Total Operating Cost, \$/hr	Unit Operating Costs, \$ per Tonne Output	
					Caged Laying Hen	Dairy Cattle
Hamada	FS-S3	4.20	0.20	4.40	42.72	133.33
	FS-1	8.40	0.40	8.80	50.00	157.14
	FS-2	12.60	0.65	13.25	50.00	155.88
	FS-3	27.30	1.42	28.72	54.29	169.94
	FS-4	42.00	2.15	44.15	55.60	173.82
	FS-5	67.20	2.43	69.63	47.37	147.83
Heil	SD45-12	8.19	0.60	8.79	46.51	146.50
	SD75-22	49.14	1.61	50.75	44.75	139.81
	SD85-25	73.71	1.81	75.52	44.40	138.57
	SD105-32	147.42	3.64	151.06	44.40	138.59

* No. 2 Fuel Oil at \$0.21 per ℓ

† Electricity at \$0.0405 per kwhr.

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TABLE F-13. SUMMARY OF ESTIMATED COSTS FOR DRYING CAGED LAYING HEN AND DAIRY CATTLE MANURES

Manufacturer	Model	Laying Hen Manure Drying Costs, $/Tonne			Dairy Cattle Manure Drying Costs, $/Tonne		
		Fixed	Operating	Total	Fixed	Operating	Total
Hamada	FS-S3	62.98	42.72	105.70	196.56	133.33	329.89
	FS-1	45.12	50.00	95.12	141.80	157.14	298.94
	FS-2	59.54	50.00	109.54	185.61	155.88	341.49
	FS-3	41.25	54.29	95.54	129.13	169.94	299.07
	FS-4	31.95	55.60	87.55	99.88	173.82	273.70
	FS-5	22.93	47.37	70.30	71.55	147.83	219.38
Heil	SD45-12	36.09	46.51	82.60	113.68	146.50	260.18
	SD75-22	28.67	44.75	73.42	89.57	139.81	229.38
	SD85-25	24.28	44.40	68.68	75.77	138.57	214.34
	SD105-32	13.69	44.40	58.09	42.73	138.59	181.32

REFERENCES - MANURE DRYING

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Mark's Standard Handbook for Mechanical Engineers, 1978. T. Baumeister, Ed. McGraw-Hill Book Company, New York.

APPENDIX G

SUMMARIES, RATION AND MANURE COMPOSITION, AND MANURE HANDLING METHODS OF THE EVALUATED FEEDING TRIALS

In the following tables, summaries of the evaluated feeding trials, ration composition, and manure composition and handling methods are presented. Tables G-1 through G-14 pertain to studies utilizing DPW as a feedstuff for laying hens and ruminants. Tables G-15 through G-25 pertain to studies utilizing broiler litter as a feedstuff for ruminants. Tables G-26 through G-31 pertain to studies utilizing beef cattle manure as a feedstuff for ruminants. Tables G-33 through G-36 pertain to studies utilizing processed animal manures as feedstuffs for ruminants.

TABLE	TITLE
G-1	Summary of Studies Used In the Evaluation of DPW as a Feedstuff For Laying Hens
G-2	Composition of Diets Used in the Evaluation of DPW as a Feedstuff for Laying Hens
G-3	Composition of DPW Used in the Evaluation of DPW as a Feedstuff for Laying Hens
G-4	Source and Dehydration Method of DPW Used in the Evaluation of DPW as a Feedstuff for Laying Hens
G-5	Summary of Studies Used in the Evaluation of DPW as a Feedstuff for Finishing Steers
G-6	Composition of Rations Used in the Evaluation of DPW as a Feedstuff For Finishing Steers
G-7	Composition of DPW Used in the Evaluation of DPW as a Feedstuff For Finishing Steers
G-8	Source and Dehydration Method of DPW Used in the Evaluation of DPW as a Feedstuff For Finishing Steers
G-9	Summary of Studies Used in the Evaluation of DPW as a Feedstuff for Dairy Cows

TABLE	TITLE
G-10	Composition of Rations Used in the Evaluation of DPW as a Feedstuff for Dairy Cows
G-11	Composition of DPW Used in the Evaluation of DPW as a Feedstuff for Dairy Cows
G-12	Source and Dehydration Method of DPW Used in the Evaluation of DPW as a Feedstuff For Dairy Cows
G-13	Summary of Studies Used in the Evaluation of DPW as a Feedstuff for Heifers
G-14	Composition of Rations Used in the Evaluation of DPW as a Feedstuff For Heifers
G-15	Summary of Studies Used in the Evaluation of as Collected Broiler Litter as a Feedstuff for Steers
G-16	Composition of Rations Used in the Evaluation of as Collected Broiler Litter as a Feedstuff for Steers
G-17	Composition and Type of Litter Used in the Evaluation of Collected Broiler Litter as a Feedstuff for Steers
G-18	Summary of Studies Used in the Evaluation of Dried Broiler Litter as a Feedstuff for Steers
G-19	Composition of Rations Used in the Evaluation of Dried Broiler Litter as a Feedstuff for Steers
G-20	Composition, Source, and Dehydration Method of Litter Used in the Evaluation of Dried Broiler Litter as a Feedstuff for Steers
G-21	Summary of Studies Used in the Evaluation of Ensiled Broiler Litter as a Feedstuff for Ruminants
G-22	Composition of Rations Used in the Evaluation of Ensiled Broiler Litter as a Feedstuff for Ruminants
G-23	Composition, Source, and Ensiling Method of Litter Used in the Evaluation of Ensiled Broiler Litter as a Feedstuff for Ruminants
G-24	Summary of Studies Used in the Evaluation of Composted Broiler Litter as a Feedstuff for Beef Heifers and Brood Cows
G-25	Composition of Rations Used in the Evaluation of Composted Broiler Litter as a Feedstuff for Beef Heifers and Brood Cows

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TABLE	TITLE
G-26	Summary of Studies Used in the Evaluation of As Collected Dried Beef Cattle Manure as a Feedstuff for Steers and Heifers
G-27	Composition of Rations Used in the Evaluation of As Collected or Dried Beef Cattle Manure as a Feedstuff for Steers and Heifers
G-28	Composition, Source, and Handling Method of Manure Used in the Evaluation of As Collected or Dried Beef Cattle Manure as a Feedstuff for Steers and Heifers
G-29	Summary of Studies Used in the Evaluation of Ensiled Beef Cattle Manure as a Feedstuff for Ruminants
G-30	Composition of Rations Used in the Evaluation of Ensiled Beef Cattle Manure as a Feedstuff for Ruminants
G-31	Composition, Source, and Ensiling Method of Manure Used in the Evaluation of Ensiled Beef Cattle Waste as a Feedstuff for Ruminants
G-32	Summary of Studies Used in the Evaluation of Aerobically Digested Swine Manure (ODML) as a Feedstuff and Tap Water Substitute for Swine
G-33	Summary of Studies Used in the Evaluation of Anaerobically Digested Animal Manures as a Feedstuff for Ruminants
G-34	Summary of Studies Used in the Evaluation of Beef Cattle and Dairy Cow Manure Screenings as a Feedstuff for Ruminants
G-35	Summary of Studies Used in the Evaluation of Cereco Products as a Feedstuff for Ruminants
G-36	Composition of Rations Used in the Evaluation of Cereco Products as a Feedstuff for Ruminants

TABLE G-1. SUMMARY OF STUDIES USED IN THE EVALUATION OF DPW AS A FEEDSTUFF FOR LAYING HENS

Source	DPW Fed, % of Total Diet	Number of Birds per Diet	Initial Age of Hens, Weeks	Duration of Study, Days	Mortality, %	Feedstuffs Reduced or Eliminated From Diet
Quisenberry and Bradley (1969)	0	40	20*	336	5.0	Soybean Meal & Sorghum
	10	40	20*	336	5.0	
	20	40	20*	336	7.5	
Flegal and Zindel (1970)	0	32	34	139	NA†	Corn & Soybean Meal
	10	32	34	139	NA†	
	20	32	34	139	NA†	
	30	32	34	139	NA†	
Flegal and Zindel (1971)	0	18	26	366	NA†	Corn & Soybean Meal
	10	18	26	366	NA†	
	20	18	26	366	NA†	
	30	18	26	366	NA†	
	40	18	26	366	NA†	
Hodgetts (1971)	0	900	18	365	NA†	Corn & Soybean Meal, Wheat, and Barley
	10.45	1800	18	365	NA†	
Pisone and Begin (1971)	0	20	20	224	25	Corn, Wheat Middlings, Soybean Meal, Alfalfa Meal, Limestone & Dicalcium Phosphate
	5	20	20	224	0	
	10	20	20	224	25	
	20	20	20	224	10	
	30	20	20	224	10	
Flegal _et_ _al_. (1972)	0	196	20	412	7.9	Corn
	12.5	196	20	412	6.9	
	25	196	20	412	7.7	

(continued)

TABLE G-1. (continued)

Source	DPW Fed, % of Total Diet	Number of Birds Per Diet	Initial Age Of Hens, Weeks	Duration of Study, Days	Mortality, %	Feedstuffs Reduced or Eliminated From Diet
Biely, et al. (1972)	0	69	28*	100	3.0	Soybean Meal & Corn
	25	73	28*	100	1.4	
Nesheim (1972)	0	30	28*	77	0	Corn
	22.5	30	28*	77	3.3	
Trackulchang and Balloun (1975)	0	32	32	150	0	Corn, Soybean Meal, Alfalfa Meal, Dicalcium Phosphate & Limestone
	12.5	32	32	150	6.3	
	25	32	32	150	12.5	

* Estimate of age based on descriptive information
† NA = information not available

TABLE G-2. COMPOSITION OF DIETS USED IN THE EVALUATION OF DPW AS A FEEDSTUFF FOR LAYING HENS

		% of Dry Matter							
Source	Diet	Crude Protein	Available Protein	Ether Extract	Ash	Calcium	Phosphorus	Crude Fiber	Metabolizable Energy, kcal/kg
Quisenberry and Bradley (1969)	Control	17.6	--	3.0	14.8	3.36	0.87	15.3	3067
	10% DPW	17.8	16.0	3.0	16.5	4.08	1.06	13.7	2756
	20% DPW	18.1	14.5	2.9	18.2	4.81	1.25	11.9	2441
Flegal and Zindel (1970)	Control	18.2	--	4.0	9.6	2.48	0.43	3.8	3446
	10% DPW	19.8	18.0	3.9	11.4	2.27	0.63	5.3	3286
	20% DPW	21.4	17.3	3.8	12.4	1.78	0.83	5.9	3096
	30% DPW	23.0	17.6	3.7	13.4	1.29	1.03	7.0	2907
Flegal and Zindel (1971)	Control	17.9	--	4.9	10.5	3.00	0.77	3.1	3471
	10% DPW	19.5	17.7	4.9	9.9	2.76	0.73	4.2	3346
	20% DPW	21.1	17.6	4.8	9.7	2.55	0.93	5.3	3205
	40% DPW	24.2	17.1	4.5	13.9	3.80	1.33	7.4	2737
Hodgetts (1971)	Control	15.2	--	2.7	8.6	2.68	0.64	2.8	2993
	10.45% DPW	15.9	14.0	2.4	10.4	2.94	0.74	3.2	2817
Pisone and Begin (1971)	Control	16.2	--	3.6	11.8	3.2	0.9	3.9	3082
	5% DPW & Lard	16.0	15.3	5.4	12.2	3.3	0.9	4.2	3053
	10% DPW & Lard	16.1	14.8	7.1	12.2	3.3	0.9	4.6	3042
	20% DPW & Lard	16.1	13.7	11.0	12.7	3.2	0.8	5.4	3042
	30% DPW & Lard	16.2	12.8	13.8	13.3	3.4	0.9	6.2	2988
Flegal *et al.* (1972)	Control	18.5	--	4.4	10.5	3.01	0.75	3.1	3446
	12.5% DPW	20.6	18.4	4.1	13.7	4.01	1.00	4.5	3130
	25% DPW	22.8	18.3	3.8	17.0	5.01	1.25	5.8	2813
Biely *et al.* (1972)	Control	16.4	--	3.9	10.2	2.73	0.66	2.3	2996
	25% DPW	16.4	12.3	4.1	9.7	2.52	0.73	4.8	3025
Nesheim (1972)	Control	15.3	--	5.0	13.1	3.91	0.84	3.1	2866
	22.5% DPW	15.4	14.6	7.0	12.2	3.36	0.86	5.5	2447
Trackulchang and Balloun (1975)	Control	16.0	--	4.3	12.9	3.56	0.94	3.0	2850
	12.5% DPW & SBO	16.0	14.4	6.1	12.2	3.35	0.89	4.3	2850
	25% DPW & SBO	16.0	13.1	7.9	11.6	3.16	0.85	5.5	2845

TABLE G-3. COMPOSITION OF DPW USED IN THE EVALUATION OF DPW AS A FEEDSTUFF FOR LAYING HENS

	---% of Dry Matter---						---Kcal/Kg---
Source	Crude Protein	Ether Extract	Ash	Calcium	Phosphorus	Crude Fiber	Metabolizable Energy
Hodgetts (1971)	32.6	1.75	27.55	7.88	2.39	11.9	--
Biely et al. (1972)	31.08	1.62	23.76	8.27	2.00	10.7	2050
Nesheim (1972)	--	--	--	7.8	2.6	--	480

TABLE G-4. SOURCE AND DEHYDRATION METHOD OF DPW USED IN THE EVALUATION OF DPW AS A FEEDSTUFF FOR LAYING HENS

Study	Source and Dehydration Method
Quisenberry and Bradley (1969)	Manure from caged laying hens fed an unspecified diet. Dehydration method not specified.
Flegal and Zindel (1970, 1971)	Manure from pullets fed a standard laying hen diet. Dehydration method not specified.
Hodgetts (1971)	Fresh manure from battery caged laying hens fed an unspecified diet. Manure dehydrated in a rotary drum type dryer to a moisture content between 12 and 18%.
Pisone and Begin (1971)	Manure from caged laying hens fed a standard laying hen diet. Dehydration method not specified.
Flegal _et_ _al_. (1972)	Manure from caged laying hens fed a typical caged-laying hen diet. Dehydration method not specified.
Biely _et_ _al_. (1972)	Manure from caged laying hens fed a standard laying hen diet. Dehydration method not specified.
Nesheim (1972)	Manure from caged laying hens fed a standard laying hen diet. Dehydrated at 60°C in a force air oven.
Trackulchang and Balloun (1975)	Manure from caged laying hens fed an unspecified diet. Dehydrated in a force air oven at 80°C for 72 hours.

TABLE G-5. SUMMARY OF STUDIES USED IN THE EVALUATION OF DPW AS A FEEDSTUFF FOR FINISHING STEERS

Source	Experimental Levels of DPW, %	Number Steers Per Ration	Steer Breed	Initial Weight of Steers, kg	Duration of Study, days	Feedstuffs Reduced or Eliminated in Ration
Long *et al.* (1969)	0	6	Angus	301.4	139	Soybean Meal & Limestone
	5	6		307.3	139	
Bucholtz *et al.* (1971)	0	9	--	313.4	134	Shell Corn, Minerals, Vitamins & Soybean Meal
	10.5	9		314.8	134	
	32	9		312.5	134	
Oliphant (1974)	0	8	Friesian	163	206	Soybean Meal, Barley & Fish Meal
	15	8		167	206	
	0	8		163	212	
	14.8 & Urea	8		163	212	
Cullison *et al.* (1976)	0	20	--	241.4	138	Soybean Meal, Minerals & Peanut Hulls
	13	20	--	241.9	152	
Oltjen and Dinius (1976)	0	4	--	238	90	Cracked Corn, Peanut Hulls, Minerals & Urea
	15-A	4		259	90	
	15-B	4		248	90	

TABLE G-6. COMPOSITION OF RATIONS USED IN THE EVALUATION OF DPW AS A FEEDSTUFF FOR FINISHING STEERS

		% of Dry Matter								Mcal/kg
Source	Ration	Crude Protein	Digestible Protein	Ether Extract	Ash	Calcium	Phosphorus	Crude Fiber	TDN	M.E.
Long et al. (1969)	Control	10.66	8.8	3.06	2.15	0.33	0.30	9.2	84.0	3.021
	5% DPW	9.65	7.7	3.15	3.26	0.56	0.39	9.7	83.0	2.989
Bucholtz et al. (1971)	Control	11.7	8.5	3.9	4.3	0.88	0.40	7.1	85.9	3.122
	10.5% DPW	11.6	8.6	3.7	7.1	1.17	0.58	8.2	82.2	2.976
	32% DPW	12.0	8.6	3.3	12.6	2.78	0.97	10.4	74.2	2.664
Oliphant (1974)	Control	14.5	9.7	2.3	4.7	0.31	0.44	9.2	76.8	2.789
	15% DPW	14.1	7.4	2.3	7.1	1.30	0.63	10.6	73.4	2.666
	Control	14.5	9.7	2.3	4.7	0.31	0.44	9.2	76.8	2.789
	14.8% DPW & Urea	14.5	8.0	2.2	7.8	1.28	0.62	10.5	72.0	2.617
Cullison et al. (1976)	Control	11.5	9.7	3.8	3.2	0.40	0.40	8.5	88.5	3.188
	13% DPW	11.9	8.2	3.9	4.6	1.10	0.54	7.1	86.0	3.109
Oltjen and Dinius (1976)	Control	11.5	9.0	2.6	7.1	0.56	0.38	27.2	61.5	2.267
	15% DPW-A	11.9	6.2	2.6	8.6	1.19	0.48	23.9	62.4	2.221
	15% DPW-B	12.0	5.6	2.6	10.3	1.55	0.49	23.9	62.4	2.221

TABLE G-7. COMPOSITION OF DPW USED IN THE EVALUATION OF DPW AS A FEEDSTUFF FOR FINISHING STEERS

Source		% of Dry Matter					
		Crude Protein	Ether Extract	Ash	Calcium	Phosphorus	Crude Fiber
Long *et al.* (1969)		24.88	2.23	27.17	9.15	2.57	10.43
Bucholtz *et al.* (1971)		17.0	--	--	--	--	--
Oliphant (1974)	15% DPW	31.8	--	--	--	--	17.8
	14.8% DPW	26.3	--	--	--	--	11.8
Cullison *et al.* (1976)		40.4	0.5	27.0	--	--	8.9
Oltjen and Dinius (1976)	A	26.88	--	25.44	6.20	8.60	--
	B	19.50	--	37.10	2.00	2.10	--

TABLE G-8. SOURCE AND DEHYDRATION METHOD OF DPW USED IN THE EVALUATION OF DPW AS A FEEDSTUFF FOR FINISHING STEERS

Study	Source and Dehydration Method
Long et al. (1969)	Commercial caged layer manure. Steamed under 30 lbs. pressure for 30 minutes. Dehydrated 1 minute at 427°C to 10 - 15% moisture content.
Bucholtz et al. (1971)	Caged layer manure. Dehydrated in a commercial dryer.
Oliphant (1974)	Source and dehydration method not specified.
Cullison et al. (1976)	Commercial caged layer manure. Dehydrated in a commercial dryer.
Oltjen and Dinius (1976)	Commercial caged layer manure. Dehydration method not specified.

TABLE G-9. SUMMARY OF STUDIES USED IN THE EVALUATION OF DPW AS A FEEDSTUFF FOR DAIRY COWS

Source	Experimental Levels of DPW, %	Number of Cows Per Ration	Breed	Duration of Study, Days	Feedstuffs Reduced or Replaced in Ration
Thomas *et al.* (1972)	0	6	Holstein	85	Oats and Soybean Meal
	4.7	6		85	
Kneale and Garstang (1975)	0	16	Friesian	168	
	8.5	16		168	Soybean Meal
	17	16		168	
	0	8		70	Barley, Soybean Meal and Peanut Meal
	10.9	8		70	
Silva *et al.* (1976)	0	6	Holstein	84	Citrus Pulp
	10	6		84	
	20	6		84	
	30	6		84	
Smith *et al.* (1976)	0	12	Holstein	90	Wheat Middlings, Gluten, Corn, Molasses, Soybean Meal, Barley, Oats, Bone Meal and Salt
	15.9	12		90	

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TABLE G-10. COMPOSITION OF RATIONS USED IN THE EVALUATION OF DPW AS A FEEDSTUFF FOR DAIRY COWS

		% of Dry Matter								Mcal/kg
Source	Ration	Crude Protein	Digestible Protein	Ether Extract	Ash	Calcium	Phosphorus	Crude Fiber	TDN	Metabolizable Energy
Thomas *et al.* (1972)	Control	19.0	14.9	2.9	5.6	0.38	0.30	22.5	69.4	3.440
	4.7% DPW	19.0	13.0	2.9	6.4	0.73	0.39	23.4	68.6	3.152
Kneale and Garstang (1975)	Control	14.3	9.9	2.0	7.2	0.36	0.35	24.4	61.0	2.321
	8.5% DPW	13.8	8.4	2.1	9.0	0.98	0.50	24.6	58.9	2.239
	17% DPW	12.5	6.1	2.1	10.7	1.58	0.63	25.3	56.2	2.127
	Control	12.8	8.6	2.3	6.7	0.33	0.31	27.7	59.4	2.938
	10.9% DPW	14.4	8.7	2.3	8.9	1.18	0.51	26.7	58.4	2.914
Silva *et al.* (1976)	Control	13.32	7.8	2.6	5.0	0.76	0.23	15.0	69.1	2.644
	10% DPW	12.91	8.7	2.3	8.8	1.36	0.45	14.7	66.8	2.564
	20% DPW	13.41	9.6	2.1	14.9	1.96	0.66	13.0	63.5	2.449
	30% DPW	14.39	10.5	1.4	19.1	2.56	0.88	12.2	60.2	2.334
Smith *et al.* (1976)	Control	17.7	14.0	3.1	5.8	0.31	0.36	18.2	73.0	3.009
	15.9% DPW	17.3	9.6	3.2	8.0	2.61	0.94	17.4	72.0	2.893

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TABLE G-11. COMPOSITION OF DPW USED IN THE EVALUATION OF DPW AS A FEEDSTUFF FOR DAIRY COWS

	% of Dry Matter					
Source	Crude Protein	Ether Extract	Ash	Calcium	Phosphorus	Crude Fiber
Kneale and Garstang (1975)	31.88	--	--	--	--	--
Silva et al. (1976)	12.9	0.7	60.3	14.4	3.2	7.6

TABLE G-12. SOURCE AND DEHYDRATION METHOD OF DPW USED IN THE EVALUATION OF DPW AS A FEEDSTUFF FOR DAIRY COWS

Study	Source and Dehydration Method
Thomas et al. (1972)	Caged layer manure fed a normal 17% protein, non-medicated diet. Dehydration in a commercial dryer.
Kneale and Garstang (1975)	Caged layer manure. Dehydrated by flash drying.
Silva et al. (1976)	Commercial caged layer manure. Dehydrated in a Coleman Industrial Manure Dryer at 315.5°C for 40 minutes.
Smith et al. (1976)	Experimental caged layer manure. Dehydration method not specified.

TABLE G-13. SUMMARY OF STUDIES USED IN THE EVALUATION OF DPW AS A FEEDSTUFF FOR HEIFERS

Source	Experimental Levels of DPW, %	Number of Heifers Per Ration	Breed	Initial Weight, Kg	Duration of Study, Days	Feedstuffs Reduced or Replaced in Ration
Cooper *et al.* (1974)	0	7	Angus	216	112	Soybean Meal
	21.9	7		216	112	
Keys and Smith (1978)	11.1 + corn silage & stover	7	Holstein	398	70	N/A*
	11.6 + corn	7		398	70	
	25.3 + corn & stover	7		398	70	

*N/A - No control ration, therefore no feedstuffs were reduced or replaced.

TABLE G-14. COMPOSITION OF RATIONS USED IN THE EVALUATION OF DPW AS A FEEDSTUFF FOR HEIFERS

	---% of Dry Matter---								Mcal/kg
Source	Crude Protein	Digestible Protein	Ether Extract	Ash	Calcium	Phosphorus	Crude Fiber	TDN	M.E.
Cooper et al. (1974)									
Control	16.5	12.1	2.5	5.7	0.51	0.38	20.6	71.8	2.600
21.9% DPW	11.6	5.6	2.7	10.2	2.04	0.72	22.8	64.6	2.345
Keys and Smith (1978)									
11.1% DPW	11.8	4.4	2.3	9.1	1.28	0.45	26.5	64.0	2.318
11.6% DPW	12.4	8.6	4.2	10.9	0.95	0.57	3.6	90.0	3.190
25.3% DPW	13.4	7.9	3.1	14.0	2.20	0.77	13.0	75.4	2.689

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TABLE G-15. SUMMARY OF STUDIES USED IN THE EVALUATION OF AS COLLECTED BROILER LITTER AS A FEEDSTUFF FOR STEERS

Source	Experimental Levels of Litter, %	Number Steers Per Ration	Initial Body Weight, kg	Duration of Study, Days	Feedstuffs Reduced or Eliminated in Ration
Noland *et al.* (1955)	0	10	305.7	56	Cottonseed Meal, Molasses & Corn
	18.72	10	305.7	56	
	0	10	350.6	56	
	18.75	10	360.2	56	
	0	10	397.8	42	
	18.77	10	393.7	42	
Southwell *et al.* (1958)	0	10	313.4	140	Snapped Corn, Cottonseed Meal & Bermudagrass Hay
	9.9	10	314.8	140	
	19.8	10	317.5	140	
Fontenot *et al.* (1966)	0	10	391	123	Hay & Soybean Meal
	25 Hulls	10	379	123	
	25 Wood	10	376	123	
Lowrey *et al.* (1975)	0	10	330	98	Peanut Hulls & Soybean Meal
	20	10	330	98	
	0	10	330	98	

TABLE G-16. COMPOSITION OF RATIONS USED IN THE EVALUATION OF AS COLLECTED BROILER LITTER AS A FEEDSTUFF FOR STEERS

		% of Dry Matter								Mcal/kg
Source	Ration	Crude Protein	Digestible Protein	Ether Extract	Ash	Calcium	Phosphorus	Crude Fiber	TDN	M.E.
Noland et al. (1955)	Control	12.9	9.7	3.6	6.0	0.35	0.46	11.0	78.7	3.102
	18.72% Litter	12.3	9.2	2.8	8.4	0.81	0.66	12.4	74.5	2.793
	Control	12.9	9.7	3.6	6.0	0.35	0.46	11.0	78.7	3.102
	18.75% Litter	12.3	9.2	2.8	8.4	0.81	0.66	12.4	74.5	2.793
	Control	13.1	9.8	3.6	5.9	0.35	0.47	10.3	79.5	3.102
	18.77% Litter	12.3	9.2	2.8	8.4	0.81	0.66	12.4	74.5	2.793
Southwell et al. (1958)	Control	11.94	8.5	3.36	1.95	.027	.028	8.76	67.0	2.511
	9.9% Litter	11.43	8.1	2.09	4.11	0.19	0.35	10.13	64.8	2.385
	19.8% Litter	10.73	9.6	1.64	6.80	0.35	0.45	6.06	72.2	2.568
Fontenot et al. (1966)	Control	13.0	9.2	3.2	4.4	0.32	0.30	13.6	78.3	2.867
	25% Hulls	14.2	10.9	3.6	6.6	0.73	0.64	9.4	81.2	2.866
	25% Wood	14.2	10.9	3.6	6.6	0.73	0.64	9.4	81.2	2.866
Lowrey et al. (1975)	Control[1]	13.1	9.6	3.7	3.8	0.56	0 58	12.6	80.4	2.851
	20% Litter	15.4	12.1	3.9	6.4	1.00	0.90	6.2	85.9	2.949
	Control[2]	11.5	8.2	3.7	3.7	0.53	0.56	15.1	77.8	2.756

TABLE G-17. COMPOSITION AND TYPE OF LITTER USED IN THE EVALUATION OF AS COLLECTED BROILER LITTER AS A FEEDSTUFF FOR STEERS

		---------------- % of Dry Matter					---------------------	
Source	Dry Matter, %	Crude Protein	Ether Extract	Ash	Calcium	Phosphorus	Crude Fiber	Type of Litter
Noland et al. (1955)	84.95	27.19	0.52	14.86	--	--	15.4	Cane Bagasse
Southwell et al. (1958)	--	19.5	1.0	--	1.48	0.99	17.9	Ground Corn Cobs
Fontenot et al. (1966)	89.1	32.0	2.8	17.9	2.77	2.86	15.1	Peanut Hulls
	88.9	30.6	2.8	19.0	2.48	2.26	14.6	Wood Shavings
Lowrey et al. (1975)	--	--	--	--	--	--	--	Wood Shavings

TABLE G-18. SUMMARY OF STUDIES USED IN THE EVALUATION OF DRIED BROILER LITTER AS A FEEDSTUFF FOR STEERS

Source	Experimental Levels of Litter, %	Number of Steers Per Ration	Initial Weight, kg	Duration of Study, days	Feedstuffs Reduced or Eliminated in Ration
Fontenot et al. (1971)	0	4	370.9	121	Timothy Hay, Corn, Alfalfa Meal, Soybean Meal, Difluorophosphate & Salt
	25	4	377.7	121	
	50	4	373.6	121	
Webb et al. (1973)	0	6	319.3	120	Ear Corn, Soybean Meal & Limestone
	25	6	309.4	120	
	25 & Molasses	6	312.1	120	
Oliphant (1974)	0	8	167	212	Barley, Soybean Meal, Fish Meal & Minerals
	14.7	8	167	234	
	0	8	163	190	
	16.1	8	161	210	
	0	8	137	234	
	23.1	8	136	284	
Cullison et al. (1976)	0	20	241.4	145	Soybean Meal, Peanut Hulls, Minerals & Molasses.
	20	20	240.6	145	
	20	20	240.3	145	
	0	19	243	145	
	0	20	219	152.5	Corn & Soybean Meal
	5.8	20	219.8	152.5	
	13	18	219.5	152.5	

TABLE G-19. COMPOSITION OF RATIONS USED IN THE EVALUATION OF DRIED BROILER LITTER AS A FEEDSTUFF FOR STEERS

		% of Dry Matter								Mcal/kg
Source	Ration	Crude Protein	Digestible Protein	Ether Extract	Ash	Calcium	Phosphorus	Crude Fiber	TDN	M.E.
Fontenot et al. (1971)	Control	15.5	11.7	3.6	4.5	0.46	0.49	9.6	83.6	2.966
	25% DBL	18.1	14.5	3.3	10.6	0.80	0.66	11.6	77.4	2.631
	50% DBL	20.7	17.3	3.1	16.6	1.14	0.84	13.7	73.0	2.298
Webb et al. (1973)	Control	13.8	11.5	3.5	4.2	0.80	0.50	43.8	80.7	2.915
	25% DBL	14.2	10.3	3.6	6.8	0.71	0.75	27.5	78.4	2.680
	25% DBL & Molasses	14.2	10.4	3.3	7.9	0.79	0.72	21.8	76.9	2.652
Oliphant (1974)	Controls	16.1	12.5	2.1	8.5	0.70	0.59	25.3	58.0	2.785
	14.7% DBL	16.0	12.6	2.2	8.8	0.59	0.51	26.6	56.7	2.602
	16.1% DBL	15.8	11.8	2.1	9.0	0.62	0.53	26.5	56.8	2.608
	23.1% DBL	15.7	12.5	2.2	9.7	0.79	0.64	26.3	57.0	2.495
Cullison et al. (1976)	Control	11.5	8.9	3.2	3.2	0.39	0.31	8.5	82.9	2.946
	20% DBL(Wood)	11.0	10.0	3.1	4.4	0.34	0.44	6.5	87.2	3.001
	20% DBL(Hulls)	11.6	10.6	3.3	5.9	0.43	0.52	5.2	87.2	3.001
	Neg. Control	8.9	7.3	3.4	2.6	0.30	0.27	8.3	84.0	2.973
	Control	10.8	8.1	3.2	3.2	0.44	0.40	7.0	84.7	3.017
	5.8% DBL	10.9	8.2	3.0	3.9	0.58	0.48	7.4	83.0	2.928
	13% DBL	11.2	8.3	3.0	4.6	0.76	0.57	8.3	80.9	2.821

TABLE G-20. COMPOSITION, SOURCE, AND DEHYDRATION METHOD OF LITTER USED IN THE EVALUATION OF DRIED BROILER LITTER AS A FEEDSTUFF FOR STEERS

Study		------- % of Dry Matter -------				Source and Dehydration Method
		Crude Protein	Ether Extract	Ash	Crude Fiber	
Fontenot et al. (1971)		--	--	--	--	Litter from commercial farm. Dried in a commercial suspension air dryer with outgoing air temperature of 121°C.
Webb et al. (1973)		--	--	--	--	Litter from commercial farm. Dried in a commercial suspension air dryer with outgoing air temperature of 132°C.
Oliphant (1974)	14.7%	27.6	--	--	28.8	Source and dehydration method not specified.
	16.1%	31.4	--	--	23.3	
	23.1%	25.9	--	--	24.9	
Cullison et al. (1976)						
Wood Shaving		22.5	1.0	22.3	--	Litter from 2 batches of birds. Air dried for several weeks to 15-18% moisture.
Peanut Hulls		24.9	0.7	32.5	--	
5.8 and 13%		34.5	2.2	19.1	--	Source not specified. Dried in-house with assistance of heated floor to 11.7% moisture.

G-21. SUMMARY OF STUDIES USED IN THE EVALUATION OF ENSILED BROILER LITTER AS A FEEDSTUFF FOR RUMINANTS

Source	Experimental Levels of Litter, %	Number and Type of Animals Per Ration	Initial Weight, kg	Duration of Study, Days	Feedstuffs Reduced or Eliminated in Ration
McClure *et al.* (1977)	0	12-Heifers	199	200	Corn silage, Shelled Corn and Soybean Meal
	12.8	12	219		
	0	12	198		
	12.8	12	215		
McClure *et al.* (1978)	0	12-Heifers	251.3	171	Corn Silage, Shelled Corn and Soybean Meal
	22.3	12	252.7		
	0	12	255.8		
	22.3	12	250.8		
Cross *et al.* (1978)	0	16-Steers	228	200	Corn Silage and Cottonseed Meal
	10	16	238		
	30	16	233		
	50	16	223		
	70 to 44	16	220		

TABLE G-22. COMPOSITION OF RATIONS USED IN THE EVALUATION OF ENSILED BROILER LITTER AS A FEEDSTUFF FOR RUMINANTS

		% of Dry Matter								Mcal/kg
Source	Ration	Crude Protein	Digestible Protein	Ether Extract	Ash	Calcium	Phosphorus	Crude Fiber	TDN	Metabolizable Energy
Heifers										
McClure et al. (1977)	Control	7.1	4.3	3.5	2.3	0.23	0.30	14.9	78.0	2.801
	12.8%	12.0	8.9	3.3	5.3	0.56	0.49	16.7	73.5	2.582
	Control & SBM*	10.1	6.6	3.0	2.8	0.33	0.32	17.2	74.5	2.685
	12.8%	14.3	10.9	3.1	5.6	0.62	0.51	17.0	73.0	2.565
McClure et al. (1978)	Control	8.5	5.0	3.4	2.1	0.25	0.29	14.2	76.3	3.027
	22.3%	14.1	10.4	3.2	7.1	0.85	0.69	15.9	69.0	2.511
	Control & SBM*	8.2	7.7	3.2	2.4	0.27	0.31	14.3	75.9	2.729
	22.3%	16.6	12.6	3.1	7.4	0.86	0.71	16.1	68.4	2.487
Steers										
Cross et al. (1978)	Control	11.1	7.9	3.6	3.4	0.22	0.44	17.2	73.3	2.601
	10%	11.1	8.9	3.7	5.4	0.50	0.61	20.5	72.4	2.517
	30%	12.1	9.0	3.5	8.1	1.10	0.83	15.6	73.4	2.476
	50%	14.4	11.5	3.6	12.0	1.60	1.20	15.6	71.6	2.316
	70 to 44%	13.3	10.7	3.9	10.4	1.40	1.09	10.6	77.2	2.530

* Soybean meal

TABLE G-23. COMPOSITION, SOURCE, AND ENSILING METHOD OF LITTER USED IN THE EVALUATION OF ENSILED BROILER LITTER AS A FEEDSTUFF FOR RUMINANTS

	------------------	------------------	% of Dry Matter	------------------	------------------	------------------	
Source	Crude Protein	Ether Extract	Ash	Calcium	Phosphorus	Crude Fiber	Source and Ensiling Method
McClure _et_ _al_. (1977)*	43.6	2.9	25.2	--	--	17.9	Litter from a commercial operation. Corn forage and litter blown into a silo. Duration of ensiling not specified.
McClure _et_ _al_. (1978)*	48.5	2.5	37.7	--	--	25.2	Same as above.
Cross _et_ _al_. (1978)	20.1	3.4	22.0	3.1	2.1	--	Litter from a poultry house raising at least 3 broods for 8 weeks each. Ensiled for 6 weeks.

* Composition after ensiling

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TABLE G-24. SUMMARY OF STUDIES USED IN THE EVALUATION OF COMPOSTED BROILER LITTER AS A FEEDSTUFF FOR BEEF HEIFERS AND BROOD COWS

Source	Experimental Levels of Litter, %	Number of Animals Per Ration	Duration of Study, Days	Feedstuff Reduced or Eliminated in Ration
Beef Heifers				
Webb et al. (1974)	0	14	130	Hay and Urea
	50	14	130	
	50 & Cu*	14	130	
	0	14	98	Hay
	75	14	98	
	75 & Cu*	14	98	
Webb et al. (1975)	0	14	140	Hay
	75	14	140	
	75 & Cu*	14	140	
Brood Cows				
Webb et al. (1974)	0	11	135	Hay
	80	11	135	
	80 & Cu*	11	135	
Webb et al. (1977)	0	14	119	Hay
	80	14	119	
	80& Cu*	14	119	
	0	12	111	Hay
	72.4	12	111	
	72.4	12	111	
Webb et al. (1978)	0	12	119	Hay
	66.7	12	119	
	66.7 & Cu*	12	119	

* Copper

TABLE G-25. COMPOSITION OF RATIONS USED IN THE EVALUATION OF COMPOSTED BROILER LITTER AS A FEEDSTUFF TO BEEF HEIFERS AND BROOD COWS

Source	Environmental Levels of Litter, %	% of Dry Matter								Mcal/kg
		Crude Protein	Digestible Protein	Ether Extract	Ash	Calcium	Phosphorus	Crude Fiber	TDN	M.E.
Beef Heifers										
Webb *et al.* (1974)	0	13.0	9.0	2.2	4.9	1.02	0.24	35.4	59.2	2.113
	50% Litter	18.1	13.7	3.2	10.1	1.32	1.16	36.6	72.0	2.354
	0	15.8	11.6	1.8	6.6	1.49	0.25	33.7	57.0	2.020
	75% Litter	22.4	18.3	2.8	14.4	1.96	1.43	28.9	65.4	1.990
Webb *et al.* (1975)	0	15.8	11.6	1.8	6.6	1.49	0.25	33.7	57.0	2.020
	75% Litter	22.4	18.3	2.8	14.4	1.96	1.43	28.9	65.4	1.990
Brood Cows										
Webb *et al.* (1974)	0	15.8	11.6	1.8	6.6	1.49	0.25	33.7	57	2.020
	80% Litter	23.6	19.8	2.8	15.2	2.09	1.51	17.4	66.1	1.974
Webb *et al.* (1977)	0	15.8	11.6	1.8	6.6	1.49	0.25	33.7	57.0	2.020
	80% Litter	23.6	19.8	2.8	15.2	2.09	1.51	17.4	66.1	1.974
	72.4% Litter	22.9	17.9	2.7	14.4	2.03	1.39	19.0	65.2	1.977
Webb *et al.* (1978)	0	15.8	11.6	1.8	6.6	1.49	0.25	33.7	57.0	2.020
	66.7% Litter	22.3	18.5	2.7	13.7	1.99	1.30	20.1	64.6	1.981

TABLE G-26. SUMMARY OF STUDIES USED IN THE EVALUATION OF AS COLLECTED OR DRIED BEEF CATTLE MANURE AS A FEEDSTUFF FOR STEERS AND HEIFERS

Source	Experimental Levels of Manure, %	Number & Type of Cattle Per Ration	Initial Body Weight kg	Duration of Study, days	Feedstuff Replaced or Eliminated in Ration
As Collected					
Anthony, 1966	0	15 Steers	250*	193	Ear Corn, Alfalfa Meal, Cottonseed Hulls & Cottonseed Meal.
	40	15	250*	193	
	0	13 Steers	250*	128	Corn Silage, Molasses & Cottonseed Meal.
	28.7	15	250*	128	
	0	13	340	94	Shell Corn, Alfalfa Meal & Cottonseed Meal.
	40	15	327.8	94	
Anthony, 1971	0	10 Steers	285	102	Corn, Cottonseed Meal, Alfalfa Meal, Molasses, Minerals & Salt.
	40	10	283	102	
	0	12	337	135	Corn, Urea, Salt & Minerals.
	40	12	336	135	
Dried					
Johnson et al. (1975)	0	6 (4 Heifers & 2 Steers)	250*	91	Cottonseed Hulls, Soybean Meal, and Urea.
	15	6	250*	91	
	10	6	250*	91	
	15	6	250*	91	
Lowrey et al. (1975)	0	10 Steers	330	98	Peanut Hulls, and Soybean Meal.
	0	10	330	98	
	20	10	330	98	

* Initial weight estimated using ADG and feed intake as per NRC requirements (1976)

TABLE G-27. COMPOSITION OF RATIONS USED IN THE EVALUATION OF AS COLLECTED OR DRIED BEEF CATTLE MANURE AS A FEEDSTUFF FOR STEERS AND HEIFERS

		% of Dry Matter								Mcal/kg
Source	Ration	Crude Protein	Digestible Protein	Ether Extract	Ash	Calcium	Phosphorus	Crude Fiber	TDN	Metabolizable Energy
As Collected										
Anthony, 1966	Control	11.8	6.8	2.7	4.1	0.23	0.40	13.0	73.1	2.638
	40% Manure	13.7	6.1	2.8	14.1	0.82	0.56	16.9	63.2	2.294
	Control	11.9	7.8	2.3	5.8	0.39	0.37	22.4	68.7	2.496
	28.7% Manure	13.2	7.0	2.5	12.5	0.77	0.49	22.4	62.9	2.290
	Control	14.7	10.9	4.1	2.2	0.09	0.38	4.3	91.6	3.170
	40% Manure	15.4	8.6	3.5	13.2	0.75	0.55	11.7	74.1	2.073
Anthony, 1971	Control	13.1	9.8	3.6	5.1	0.44	0.53	4.3	87.2	3.099
	40% Manure	15.4	7.9	3.5	14.7	0.95	0.64	11.6	71.7	2.570
	Control	11.5	10.5	4.3	3.7	0.04	0.29	2.3	91.7	3.242
	40% Manure	11.5	6.8	3.8	12.5	0.71	0.50	10.5	76.4	2.727
Dried										
Johnson et al., 1975	Control	14.9	11.0	2.6	3.8	0.36	0.37	9.0	80.4	2.881
	15% Manure	16.5	7.3	2.8	7.7	0.59	0.48	5.7	79.9	2.888
	10% Manure	16.1	7.1	5.2	6.4	0.52	0.44	6.8	80.1	2.886
	15% Manure	13.0	8.1	2.8	7.6	0.59	0.45	7.7	79.0	2.949
Lowrey *et al.*, 1975	Control	13.1	9.6	3.7	3.8	0.56	0.58	12.6	80.4	2.851
	Control	11.5	8.2	3.7	3.7	0.53	0.56	15.1	77.8	2.756
	20% Manure	13.3	8.6	4.0	8.6	0.82	0.70	6.5	83.8	2.979

TABLE G-28. COMPOSITION, SOURCE, AND HANDLING METHOD OF MANURE USED IN THE EVALUATION OF AS COLLECTED OR DRIED BEEF CATTLE MANURE AS A FEEDSTUFF FOR STEERS AND RUMINANTS

		--------- % of Dry Matter ----------				
Source	Dry Matter, %	Crude Protein	Ash	Calcium	Phosphorus	Source and Method of Handling
As Collected						
Anthony (1966)	--	--	--	--	--	Manure from beef cattle fed a high concentrate ration. Manure collected and blended daily and stored in sealed containers until the following day, when it was fed.
Anthony (1971)	25.22 28.97	19.32 16.84	-- 7.6	-- 0.22	-- 0.88	Feedlot manure from fattening cattle. Method of handling not specified.
Dried						
Johnson et al. (1975)	--	--	--	--	--	Feedlot manure from fattening cattle collected in a very wet state in the spring. Dried and ground prior to incorporation into the rations.
Lowrey et al. (1975)	--	--	--	--	--	Feedlot manure from fattening cattle. Dehydration method not specified.

TABLE G-29. SUMMARY OF STUDIES USED IN THE EVALUATION OF ENSILED BEEF CATTLE MANURE AS A FEEDSTUFF FOR RUMINANTS

Source	Experimental Levels of Manure, %	Number and Type of Cattle Per Ration	Initial Body Weight kg	Duration of Study, days	Feedstuff Reduced or Eliminated in Ration
Anthony (1968)	0	12-Steers	300*	140	Corn, Alfalfa Meal, Corn Silage, Molasses, Cottonseed Meal and Hulls.
	22.8	12	300	140	
Anthony (1969)	0	12-Steers	250*	126	Soybean Meal, Alfalfa Meal, Molasses, Minerals, and Salt.
	20.6	12	250*	126	
	0	12	250*	110	Cottonseed Meal, Molasses, Minerals, and Salt.
	11.4	12	250*	110	
	22.8	12	250*	110	
	22.8	12	250*	110	
	34.2	12	250*	110	
Anthony (1971)	0	10-Steers	285	102	Corn, Cottonseed Meal, Alfalfa Meal, Molasses, Minerals, and Salt.
	21.1	10	284	102	
	22.8	10	285	102	
	0	12	337	135	Corn, Soybean Meal, Urea, Minerals and Salt.
	22.8	11	343	136	
	21.5	11	346	136	
	21.9	11	342	136	
	16.4	11	346	136	Corn, Urea, Minerals, and Salt.
	22.8	12	342	135	
	23	12	337	135	
Westing and Brandenberg (1974)	0	15-Steers	238	184	Alfalfa Meal, Corn and Urea.
	14	15	238	184	

(continued)

TABLE G-29. (continued)

Source	Experimental Levels of Manure, %	Number and Type of Cattle Per Ration	Initial Body Weight, kg	Duration of Study, days	Feedstuff Reduced or Eliminated in Ration
Harpster et al. (1975)	0	12-Steers	258	200	Corn Silage, Corn and Soybean Meal.
	24	12	258	200	
	41.7	12	258	200	
	60	12	258	200	
Hill et al. (1975)	0	11-Steers	300*	112	Corn and bermudagrass hay.
	20	11	300*	112	
	40	11	300*	112	
	60	11	300*	112	
Newton et al. (1975)	0	9-Heifers	212	112	Corn, bermudagrass hay and urea.
	40	9	212	112	
Harpster et al. (1978)	0	16-Steers	258	183	Corn silage and soybean meal.
	24	8	258	183	
	30	16	258	183	
	45	8	258	183	

* Initial weights estimated using reported feed intake and average daily gains and NRC Tables (1976)

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TABLE G-30. COMPOSITION OF RATIONS USED IN THE EVALUATION OF ENSILED BEEF CATTLE MANURE AS A FEEDSTUFF FOR RUMINANTS

		% of Dry Matter								Mcal/kg
Source	Ration	Crude Protein	Digestible Protein	Ether Extract	Ash	Calcium	Phosphorus	Crude Fiber	TDN	Metabolizable Energy
Anthony (1968)	Control	9.9	5.7	3.0	4.5	0.26	0.38	20.7	70.2	2.624
	22.8% Manure	12.6	6.1	3.3	8.8	0.48	0.53	15.6	71.1	2.590
Anthony (1969)	Control	13.5	10.0	3.7	4.6	0.40	0.40	3.5	88.7	3.152
	20.6% Manure	14.1	9.5	3.5	7.9	0.44	0.38	10.7	66.6	2.794
	Control	12.6	6.0	2.9	6.8	0.48	0.56	15.1	68.5	2.665
	11.4% Manure	11.7	7.6	4.3	5.2	0.27	0.39	7.1	81.3	3.066
	22.8% Manure	12.4	7.3	3.9	8.7	0.49	0.43	11.8	73.8	2.772
	22.8% Manure	12.4	7.3	3.7	8.6	0.48	0.40	11.8	77.5	2.772
	34.2% Manure	13.2	6.9	3.4	12.2	0.70	0.44	16.5	68.8	2.478
Anthony (1971)	Control	13.1	9.8	3.6	5.1	0.44	0.53	4.3	87.2	3.099
	15.8% Manure	15.1	9.6	3.5	8.5	0.58	0.45	12.1	77.0	2.754
	22.8% Manure	10.6	7.3	3.7	8.6	0.48	0.40	11.8	77.5	2.768
	Control	11.5	10.5	4.3	3.7	0.23	0.64	2.3	91.7	3.242
	22.8% Manure	12.4	7.3	3.7	8.6	0.48	0.39	11.8	77.5	2.768
	21.5% Manure	14.3	9.1	3.6	8.5	0.47	0.41	11.6	77.7	2.777
	21.9% Manure	14.8	9.7	3.6	9.3	0.57	0.49	11.5	76.3	2.753
	16.4% Manure	14.6	10.0	3.8	7.7	0.48	0.47	9.2	80.4	2.863
	22.8% Manure	11.8	7.3	3.7	8.6	0.18	0.45	11.8	77.5	2.768
	23% Manure	10.9	7.3	3.7	8.6	0.09	0.42	11.8	77.5	2.768
Westing and Brandenberg (1974)	Control	12.3	7.1	5.0	4.6	0.58	0.30	10.5	78.5	2.924
	14% Manure	14.7	6.0	8.8	10.4	0.89	0.35	12.1	74.6	2.980
Harpster et al. (1975)	Control	10.4	6.9	3.1	4.2	0.24	0.33	17.0	74.6	2.768
	24% Manure	11.7	6.6	3.5	8.8	0.47	0.44	12.3	76.0	2.735
	41.7% Manure	12.5	5.8	3.1	14.2	0.82	0.50	19.4	64.1	2.313
	60% Manure	13.3	4.9	2.8	19.8	1.18	0.56	26.9	51.9	1.874
Hill et al. (1975)	Control	11.0	7.5	4.2	3.5	0.48	0.28	5.9	85.0	3.017
	20% Manure	11.7	7.0	3.9	9.1	0.81	0.39	9.0	80.0	2.769
	40% Manure	13.1	6.5	3.6	14.5	1.13	0.49	12.6	71.7	2.521
	60% Manure	14.2	6.1	3.3	19.9	1.45	0.59	29.1	63.5	2.273
Newton et al. (1975)	Control	13.4	10.1	4.0	2.7	0.12	0.28	7.5	84.8	3.062
	40% Manure	14.6	8.1	3.5	13.3	0.75	0.49	13.6	70.3	2.549
Harpster et al. (1978)	Control	11.3	7.6	3.5	2.2	0.18	0.31	22.1	83.3	2.974
	24% Manure	12.5	7.2	3.7	8.9	0.50	0.40	11.7	77.4	2.809
	30% Manure	13.9	7.0	3.8	5.0	0.61	0.43	14.1	73.0	2.617
	45% Manure	13.2	6.6	3.1	15.4	0.89	0.49	19.9	62.1	2.246

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TABLE G-31. COMPOSITION, SOURCE, AND ENSILING METHOD OF MANURE USED IN THE EVALUATION OF ENSILED BEEF CATTLE WASTE AS A FEEDSTUFF FOR RUMINANTS

Study	Dry Matter, %	---------- % of Dry Matter --------- Protein	Ash	Calcium	Phosphorus	Source and Treatment
Anthony (1968, 1969)	--	--	--	--	--	Fresh manure from full fed slaughter cattle and ensiled with ground costal bermudagrass hay (57:43 Ratio).
Anthony (1971)	21.02	14.84	--	--	--	
	20.14	16.19	--	--	--	
	25.15	13.37	6.89	0.16	0.51	The 23% manure ration (1971) was ensiled with corn and hay.
Westing and Brandenberg (1974)	--	15.0	--	3.02	0.76	Manure from feedlot steers fed high energy ration. Composted in a covered 1.5 m high pile for 60 days.
Harpster et al. (1975)	--	16.5	--	--	--	No source specified. Manure ensiled with chopped grass hay (60:40 ratio) for unspecified duration.
Hill et al. (1975)	--	--	--	--	--	No source specified. Wet manure ensiled with 40, 60 or 80% of control ration for unspecified duration.
Newton et al. (1975)	--	--	--	--	--	No source specified. Manure ensiled with 60% of control ration for unspecified duration.
Harpster et al. (1978)	--	--	--	--	--	Manure from Angus and Angus-Hereford Steers fed 2 kg. long hay and ad lib. ground shelled corn. Ensiled with hay (60:40) for unspecified duration.

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TABLE G-32. SUMMARY OF STUDIES USED IN THE EVALUATION OF AEROBICALLY DIGESTED SWINE MANURE (ODML) AS A FEEDSTUFF AND TAP WATER SUBSTITUTE FOR SWINE

Source	How Utilized	Experimental Level, %	Number of Animals	Duration of Study, Days	Feedstuff Reduced or Eliminated in Ration
Harmon *et al.* (1973)	Feedstuff	0	38	56	Corn, soybean meal, minerals, and vitamins,
		6.0	38	56	
		0	12	56	Corn.
		5.7	12	56	
Harmon and Day (1974)	Tap Water Substitute	0	60	87	None.
		4.7-5.3	60	87	
Harmon and Day (1975)	Tap Water Substitute	2.8	56	56	None.
		2.8	64	77	

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TABLE G-33. SUMMARY OF STUDIES USED IN THE EVALUATION OF ANAEROBICALLY DIGESTED ANIMAL MANURES AS A FEEDSTUFF FOR RUMINANTS

Source	Product	Experimental Levels of Product, %	Number of Animals per Group	Duration of Study, Days	Feedstuff Replaced or Eliminated in Ration
Burford and Varani (1978)	Wet Cake	0	36	77	Cottonseed Meal, Straw and Limestone
		18	36	77	
Prior and Hashimoto (1980)	Digestor Effluent	0-Positive control	10	168	Soybean Meal
		6.45	10	168	
		0-Negative control	10	168	

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TABLE G-34. SUMMARY OF STUDIES USED IN THE EVALUATION OF BEEF CATTLE AND DAIRY COW MANURE SCREENINGS AS A FEEDSTUFF FOR RUMINANTS

Source	Type of Screenings	Experimental Level, %	Number and Type of Cattle Fed	Duration of Study, Days	Feedstuff Reduced or Eliminated in Ration
Richter & Shirley (1977)	Beef Cattle Manure	0	4-Steers	124	Corn, Citrus Pulp, Cottonseed Meal and Hulls, Molasses and Fat
		20	4	124	
		40	4	124	
		60	4	124	
Schake et al.	Beef Cattle Manure	0	22-Brood Cows	59	Sorghum, Sudangrass hay and Molasses.
		39	21	59	
		60.5	21	59	
		74.5	20	59	
		74.5	20	30	
		86.5	20	29	
Johnson et al. (1975)	Dairy Manure	33	10-Steers	28	Corn silage.
		45	10	28	
		0	8-Steers	75	
		30	8	75	
Oliveria et al. (1977)	Dairy Manure	0	20-Heifers	3.6 mo.	Corn silage
		50(ensiled)	20	3.3 mo.	
		30	8-Steers	102	
		30(ensiled)	8	102	

TABLE G-35. SUMMARY OF STUDIES USED IN THE EVALUATION OF CERECO PRODUCTS AS A FEEDSTUFF FOR RUMINANTS

Source	Product Fed	Experimental Level Fed, %	Number of Steers	Breed of Steer	Initial Body Weight, kg	Duration of Study, days	Feedstuff Reduced or Eliminated in Ration
Lambeth *et al.* (1974)	Control	0	75	Hereford, Angus, and Hereford-Angus cross.	377.8	91	Corn silage and protein supplement.
	CII	8	75		368.3	91	
	CII & Urea	4	75		375.4	91	
	Negative Control	0	75		375.8	91	
Lambeth (1975)	Control	0	300	--	356.1	135	
	CI	8.3	300	--	351.5	135	Corn silage.
	CII	3.9	300	--	356.1	135	Protein supplement.

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TABLE G-36. COMPOSITION OF RATIONS USED IN THE EVALUATION OF CERECO PRODUCTS AS A FEEDSTUFF FOR RUMINANTS

Source	Ration	-------- % of Dry Matter -------			------ meg cal -----------	
		Crude Protein	Calcium	Phosphorus	Net Energy Production	Net Energy Maintenance
Lambeth _et_ _al_. (1974)	Control	10.78	0.47	0.32	52.6	82.7
	8% C-II	10.65	0.61	0.36	52.9	82.6
	4% C-II & Urea	10.80	0.49	0.33	53.0	83.1
	Negative Control	9.45	0.29	0.29	53.9	84.5
Lambeth (1975)	Control	10.56	0.51	0.32	54.0	83.0
	8.3% C-I	10.65	0.51	0.31	53.9	83.0
	3.9% C-II	10.42	0.50	0.30	53.7	82.9

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